FROM ABANDONMENT TO REGENERATION: LANDSCAPE AGENTS IN POST-INDUSTRIAL SITE TRANSFORMATION

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ABSTRACT
The transformation of abandoned or unused areas in cities is a global phenomenon, especially in the post-industrial era. Due to previous industrial activity, the post-industrial landscape features impaired resources or contamination, damaging the surrounding neighborhood. This is a challenge for transforming those sites to reintegrate into the city and serve the neighborhood without impacting local identities. Like most post-industrial sites, Radford's former foundry, Virginia, had been abandoned and negatively impacted public health as well as the environment. Contaminated by toxic substances such as Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs), and polychlorinated biphenyls (PCBs) foundry redevelopment requires studying the site's hazardous condition and developing a new approach within the perspective of "New Natural Resource Economics" (NNRE). NNRE involves using landscape elements as an economic base to diversify local economics, preserve the environment, and enhance social connections. Through literature review and case studies, this research aims to develop a design investigation to identify an appropriate landscape agent to address the contaminated Radford foundry. The goal is to provide a social and economic service for the city and communities within the NNRE framework for brownfield reclamation. The research identified the landscape agents, industrial hemp, Miscanthus Spp., and Populus Spp., that can bridge contamination, form a rotation landscape that recycles the nutrients in the soil, and facilitate a circular economy and growth for the community and the city. In conclusion, the paper provides alternative perspectives from academics and design professionals for brownfield reclamation and municipal design decisions in small rural cities and towns.

Keywords
Sustainable Rural Economies, Socioeconomic Transitions, Economic Viability, New Natural Resources Economic (NNRE), Post-Industrial Site

1 INTRODUCTION

Post-industrial transformation is the global trend of reclaiming valuable land resources for new development (Martinat et al., 2018) taking into consideration the increased pollution and public health problems negatively impacting human life and social prosperity (Pecina et al., 2021). Brownfield development has emerged with the intensification of urban sprawl. In both Europe and North America, redevelopment and land transformation programs, such as the Superfund from EPA and Sustainable Urban Planning and Economic Redevelopment (SUPER), help to optimize the transformation method to meet the planning goals and future development plans associated with the desired social, economic and environmental benefits (Chen et al., 2009; Loures, 2015). However, due to the former foundry production and college-oriented conditions, brownfield reclamation is site-specific and driven by city planning and vision (Loures, 2015). The process faces numerous challenges such as soil contamination, long-term maintenance, and land acquisition. Furthermore, the post-industrial transformation is an ongoing investment process. It highly relies on federal and local government financial support, which can be demanding for small cities and rural towns dealing with the financial challenges. Therefore, it is necessary to consider how these former industrial sites can achieve economically, environmentally, and socially sustainable development within a local context.

1.1 City of Radford

Radford is the center of New River Valley, well known for its abundant natural resources, and is the home of Radford University. Historically, Radford experienced three major transformations that have formed the city's character. The establishment of Radford in the early 20th century was based on the construction industry, manufacturing, and the many emerging natural resources-based industries, such as textiles, wood, and grain. In the mid-20th century, manufacturing, such as Radford Ordnance, Graflo Rubber, and Radford Foundry, accelerated the town’s development followed by tourist and educational service-oriented businesses in the early 21st century (David Ridpath, 2017). However, historical manufacturing was detrimental to the environment, resulting in soil and water contamination. As the city transformed and factories closed or moved out, existing contamination posed a potential threat to public health.

1.2 Radford recreational resources

As a college town, Radford is largely influenced by Radford University, especially in terms of its population. In 2021, the total population of Radford was around 16,499 (bureau, 2021), while the total enrollment of Radford University had 7,718 students in the 2021 academic year, which make up almost 50% of the overall population in the city. According to Gumprecht's (2009) findings, when students account for more than 20% of people, the town becomes anchored around the university (Almond, 2020). This reveals the close relationship between the city and Radford University, which that Radford University cannot only brings an influx of new population but also drives economic activities each year. Due to this strong connection, urban redevelopment heavily relies on university communities for economic development and social vitality, resulting in imbalanced amenity allocations.

The urban green space is one piece of evidence that illustrates this relationship. As shown in Figure 1, the service coverage of urban green space, including public parks and athletic fields, is larger on the university campus side (east side of the city) than on the residential side (west side of the city). Furthermore, the most dominant use of urban green space is the Athletic field, which accounts for 35% of the city. These green fields are used for sports practices and seasonal big sports events for Radford University. Other commonly used green spaces include public parks, walking trails, and nature parks that offer various outdoor activities such as picnics, dog walks, jogging, and water recreation activities for residents. However, the main challenge on the residential side is that urban green space has not been fully utilized due to the limited functional settings and recreational activities for the community. For example, both Sunset Park and Howard M. Sisson Park are green lawn areas that solely provide playground-related activities without consideration of pedestrian access, age groups, and leisure purposes. Riverview Park faces similar challenges regarding the limited availability of leisure activities in a green lawn-based setting; however, it differs in its location, being situated near the river, which provides access to kayaking opportunities. To fulfill the purpose of neighborhood parks, they should be designed to cater to the needs of people in residential neighborhoods and provide sufficient facilities to accommodate a wide range of visitors (Seeley, 1973). Therefore, it is important to consider that the urban green space enables local residents to have diverse outdoor recreational opportunities while attracting visitors from university communities.

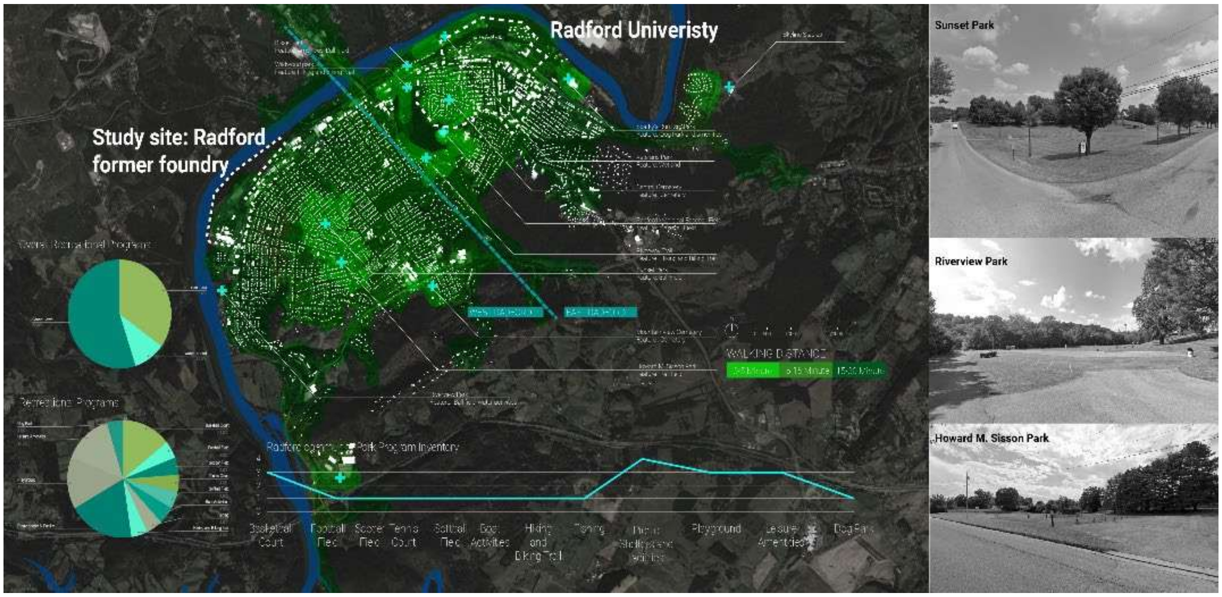

Figure 1. Radford recreational service analysis. Diagram by the authors.

1.3 The obstacle of brownfield reclamation

Main Street Radford, built along the new river, has always been the center of commercial activities for residents. The recent planning goal is to develop an enterprise zone that is mixed with a commercial zone in the main street corridor. However, the former Radford foundry is situated in one parcel that breaks the linkage in the corridor, which required a new transformation that allowed it to be part of the planning scheme. This is cost-prohibitive to the brownfield reclamation and further development due to the contamination issue and cost of removing existing facilities (Hill Studio, 2009). Partnering with multiple stakeholders, such as Radford University, Main Street Radford, The Industrial Development Authority, and the City of Radford itself, is considered as a solution for cost-prohibitive transformation (Hill Studio, 2009).

However, the city's weak consumer spending and stagnant revenues might impact the partnership and the brownfield redevelopment process. Firstly, Radford University is the city's largest employer and significantly influences the local community. The most noticeable impact of the brownfield redevelopment is the decreased enrollment at Radford University. The decline in enrollment beginning in 2020 has contributed to stagnant population growth in the city, a reduction in local revenue, diminished tourism, and subsequent business closures (Services, 2022). Second, the 2022 financial statements highlight that decreased enrollment has significantly impacted local revenue, particularly through reductions in general property taxes and local taxes. This decline has necessitated budget cuts across various governmental operations, including governmental and business activities (Services, 2022). Third, the high poverty rate of 35.39% in 2020 and low median earnings in three major employment sectors in the city (Figure 2) increased the burden of investing in cost-prohibitive brownfield redevelopment. As the partnership strategies across all stakeholders are mainly concentrated on attracting new private investment or finding finance for new infrastructure and facilities rather than utilizing the brownfield for alternative revenue while processing brownfield reclamation, it requires further consideration in the development strategies with more than cleaning contamination but if it is socially and economically resilience enough for city and local communities in a difficult era.

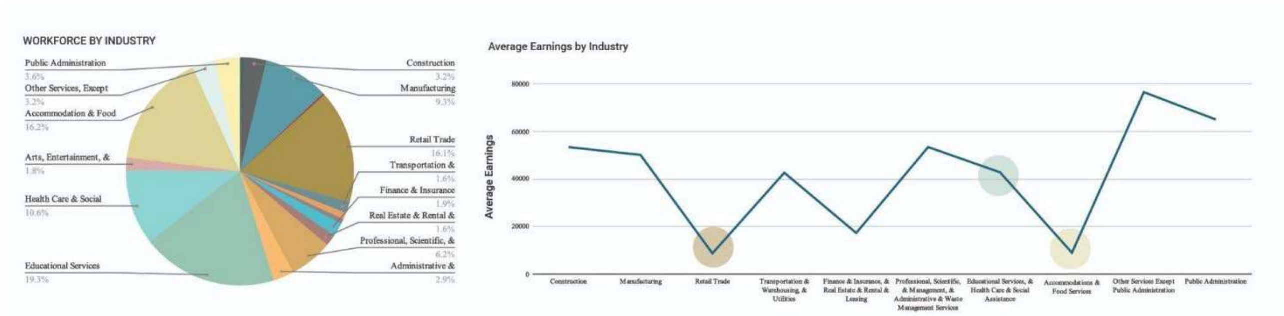

Figure 2. Radford workforce by industry and average earnings by industry. Diagram by the authors.

1.4 The former Radford Foundry

The site of the former Radford foundry is about 121.7 acres, including the landfill area. It is located on the west side of the city next to the New River. The site was developed as an iron foundry in the 1890s and operated in various guises until it was abandoned in 2003. The revitalization of Radford Foundry was put on the agenda for collaboration between the city, the foundry owner, and the Department of Environmental Quality (DEQ) with the aim of incorporating green infrastructure and green building techniques to transform the site as a new connection between the New River and outdoor recreational areas (David Ridpath, 2017).

The former Radford Foundry revitalization is part of the future development plan to attract new businesses and high-end tech companies, but the onsite pollution negatively impacts public health, which makes the transformation process difficult. As a result, Radford Foundry remains a polluted brownfield with the pollutant source, landfill, and contaminated soil constantly impacting the local community and causing residents to seek safe and secure accommodation elsewhere.

1.5 Environmental threats

The contamination has accumulated over many years due to land use. According to the Virginia Iron, Coal & Coke Company Records, the site was originally used for coal mining, iron mining, and furnace operations from approximately 1910 until the 1940s. In 1966, The Radford Foundry was established as a mold-casting operation that closed in 2003 (EPA, 2015). Mold casting involves melting and remodeling metals(EPA, 2015). According to Table 1 from the EPA reports, the contamination in concentration is above appropriate protective risk-based levels in groundwater, surface soil, surface water, and substrate soil (EPA, 2015). The contaminants are varied in terms of the natural media and previous operational location. However, the key contaminants are volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and inorganic, polychlorinated biphenyls (PCBs). Landfill waste is only in specified landfill sites (EPA, 2004, 2015).

Table 1. The major contaminant in The Radford Foundry (EPA, 2015)

Media	Key Contaminants
Groundwater	VOCs, S
Surface Soil (e.g. <2 ft.)	SVOCs, inorganics, PCBs
Surface Water	SVOCs, inorganics
Substrate Soil (e.g. >2 ft.)	Landfill waste materials
Air (outdoors)	Air emissions regulated under Title V permit

1.6 Threats toward public health

The three major contaminants—VOCs, SVOCs, and PCBs— along with other inorganic materials in the Former Radford Foundry Site, present a huge challenge for the brownfield transformation, polluting the New River, and representing a threat to public health.

Volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) are human-made chemicals used during the process of metal casting, especially in the automobile manufacturing industry. However, closed landfill that is filled with used sand, broken cores, carbide slag, cupola slag, used refractory, baghouse dust, used air pollution bags or filters, and used grinding wheels (EPA, 2015) can also produce VOCs and SVOCs during the degradation process. These contaminants have high vapor pressure and low water solubility, so they can be transported long distances in the environment (David & Niculescu, 2021), and they can remain in the soil and accumulate in surface water or groundwater. VOCs and SVOCs can be harmful to public health due to their toxicity, carcinogenicity, and other properties (David & Niculescu, 2021; Spengler & Chen, 2000). VOCs can enter the human body through inhalation and skin contact, resulting in long-term damage to the liver, kidney, and central nervous system (EPA, 2023).

Polychlorinated biphenyls (PCBs) are a group of human-made organic chemicals with a combination of carbon, hydrogen, and chlorine atoms (Borja et al., 2005; EPA, 2023). Their molecular structure makes them hard to break down once in the environment, so they remain for a long time in the biogeochemical cycle (EPA, 2023; Lang, 1992). PCBs accumulate not only in the natural environment but also in adipose tissue in humans and animals (EPA, 2023), leading to a high chance of cancer, cognitive deterioration, and metabolic disorders in humans (Zwiernik et al., 2010).

The inorganic material at the Radford Foundry site also poses a high risk to public health. Inorganics have been identified in groundwater, surface soil, and surface water (EPA, 2004). There are also some inorganic materials in groundwater (EPA, 2004). There is a potential discharge of contamination from groundwater to the New River at the downstream boundary of the site (EPA, 2004),but different organic material occurs in different natural media.

Despite the abundance of recreational resources, including a neighborhood park that serves residents, public use of the abandoned Radford Foundry is of concern. Because the foundry was used to operate metal casting for automobile component products, soil and water have become polluted with VOCs, SVOCs, inorganic materials, and PCBs and these pollutants remain on the site (EPA, 2015). Furthermore, the landfill that was built to receive waste during the operation of the foundry and after it was demolished also contains contaminants. On the other hand, the abundance of recreational resources and Radford University attract new visitors and boost the local economy. However, this is contingent on suitable development and—especially in the post-Covid era—economic recovery. Radford Foundry's redevelopment is an opportunity to deal with onsite pollution while facilitating the improvement and development of local services both socially and economically.

2 LITERATURE REVIEW AND CASE STUDIES

2.1 The new natural resources economic

The concept of the Circular Economy has garnered significant attention among scholars, industries, and governments (Padilla-Rivera et al., 2020). This approach emphasizes sustainable development through an alternative flow model that prioritizes economic systems and environmental benefits, ultimately fostering a new business model for society and its stakeholders (Geisendorf & Pietrulla, 2018; Padilla-Rivera et al., 2020). However, while it offers promising pathways for environmental and economic advancement, the Circular Economy often falls short in addressing social dimensions, such as socioeconomic factors and overall social well-being (Padilla-Rivera et al., 2020). Moreover, significant challenges persist in brownfield redevelopment due to prohibitive contamination costs, limited appeal for capital and investment in rural areas, and the lack of deal flow and support networks for entrepreneurs in future development efforts (Gibilaro & Mattarocci, 2023; Hughes et al., 2005). As a viable alternative, this research highlights The New Natural Resources Economy (NNRE), which aims to diversify rural economies while simultaneously enhancing environmental, social, and cultural assets (Hibbard & Lurie, 2013). NNRE is achieved through multifunctional landscapes that leverage local natural resources to facilitate overlapping services related to production, consumption, and protection (Hibbard & Lurie, 2013). Thus, implementing NNRE in brownfield reclamation is particularly significant, offering multiple benefits that address brownfield contamination, provide outdoor services for local residents, and ensure the sustainable development of the local economy.

2.2 Case study

In brownfield redevelopment practices, particularly landfill reclamation, the application of multifunctional landscape methods has shown significant potential in addressing environmental challenges while also facilitating new social services and economic benefits. A notable example is the Ciliverghe landfill project in Brescia, Italy. This closed landfill, covering approximately 10 hectares and containing over one million tons of waste, aims to address environmental contamination and achieve resilience and self-sufficiency within the park. The project prominently features the use of oleaginous crops, such as Rapeseed (Brassica napus), Sunflower (Helianthus annuus), and Soybean (Glycine max), to enhance the landfill's visual aesthetics and control leachate. By recycling landfill leachate to irrigate these selected crops, the project controls leachate leakage, as the fertilizing elements within the leachate promote plant growth (Artuso & Cossu, 2018). Laboratory research on the phytotreatment of these crops has confirmed their effectiveness, with significant removal rates of Chemical Oxygen Demand (COD) ($\eta > 80\%$), total nitrogen ($\eta > 70\%$), and total phosphorus ($\eta > 95\%$), while also producing larger plant biomass when irrigated with leachate (Lavagnolo et al., 2016). Moreover, oleaginous crops are ideal for energy production, providing seeds for biodiesel and ligneous material for thermal energy generation (Artuso & Cossu, 2018). Ultimately, the plants operate under a net energy metering system with a power output of 200 kWp, offering the potential to supply power to other municipal uses and generate electricity (Artuso & Cossu, 2018).

The Freshkills Park project aims to reclaim the world's largest sanitary landfill, spanning approximately 3,000 acres, and transform it into a city park that offers significant social benefits to residents and the city. A key strategy employed to address soil contamination and improve soil quality is strip cropping, which reduces the need for large quantities of new topsoil. Strip cropping takes advantage of the life cycle of selected plant species by rotating them into the soil, thereby enhancing soil nutrients as organic material is generated during the process (Yin et al., 2017). This approach not only improves poor soil quality but also aerates compacted soil, facilitating the growth of native grasses (Corner, 2005). In a study by Klenosky, a mail survey was conducted to assess visitor perceptions of the project. The results revealed that 73% of respondents believed the transformation would improve the natural environment, 67% felt it would enhance the quality of life on Staten Island, and 60% agreed it would positively impact the living conditions of Staten Island residents (Klenosky et al., 2017).

In contrast, the reclamation of the 840-hectare Hiriya Landfill in Tel Aviv addresses several environmental challenges, including preventing groundwater pollution from landfill leachate, ensuring slope stability, and managing biogas emissions, while also generating substantial economic benefits. Notably, utilizing harmful resources during the reclamation process can have a positive financial impact on the surrounding area. Research on the economic aspects of the Hiriya landfill rehabilitation indicates that the landfill can produce 390 million cubic meters of gas, with over 50% being methane that can be collected and sold, yielding an estimated present value of approximately US$20 million over 20 years (Ayalon et al., 2006). Additionally, landscape interventions, such as introducing drought-tolerant plants, olive groves, and orchards, not only enhance slope stability and transform the area into a public park but also potentially increase property values within a 5-kilometer radius, with total benefits reaching up to US$165 million (Ayalon et al., 2006). Furthermore, the park is expected to increase the average willingness to pay for park services by about US$12.20 per family annually (Ayalon et al., 2006).

2.3 Research gaps, objectives, method

The NNRE concept and its application in brownfield redevelopment projects highlight the multifaceted benefits of integrating multifunctional landscapes into environmental, social, and economic development. However, given that contaminants, social contexts, and cultural backgrounds vary significantly across different brownfields, it is crucial to tailor the concept and strategies to meet local needs. Investigating brownfield redevelopment in a rural college town is particularly valuable, as such towns often rely heavily on their college industries. This reliance can create a situation where the town's development is closely tied to the university, rather than fostering a balanced coexistence with off-campus services and a vibrant urban experience for all residents and visitors.

This research focuses on investigating the role of landscape agents in addressing on-site contaminants, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), inorganic materials, and polychlorinated biphenyls (PCBs), while also exploring their potential to enhance social services and economic benefits. Utilizing the NNRE framework, the investigation is organized into three principal areas: (1) the effectiveness of phytoremediation using various landscape agents to manage contamination at Radford Foundry and their role in preserving soil nutrients, (2) the potential for enhancing recreational outdoor services with the introduction of these landscape agents, and (3) the possible economic benefits associated with the use of these plants during the brownfield reclamation process and their future contributions to local economic development. This research involves site-specific design investigations, with contamination data sourced from the EPA report on Radford Foundry and census data from the U.S. Census Bureau 2021. Additionally, spatial analysis of urban green space services in Radford is conducted using the City of Radford's open GIS data. Literature review and case studies will follow to select suitable plant species that can adapt to contaminated brownfield conditions and enhance social and economic services.

3 METHOD: DESIGN RESEARCH INVESTIGATION

3.1 Implementation of the New Natural Resources Economic (NNRE) framework in Radford

The NNRE framework highlights using natural resources to foster social and economic service benefits. Biologically, plant species can help alleviate the contamination level of brownfields and control pollution. Socially, the brownfield thus transformed and reclaimed can be turned into urban parks. Economically, the plants can be locally used or exported, thus performing a local environmental service.

Therefore, energy crops are the major agent for implementing the NNRE in the Radford brownfield reclamation. Energy crops such as *Populus* trees, *Miscanthus* grasses, and industrial hemp (*Cannabis sativa L.*) are good choices for cultivation because they perform a phytoremediation function in reclaiming the polluted brownfield site. Given the site's varied conditions, it has been divided into seven distinct zones to implement bioremediation and planting strategies. Industrial hemp will be planted at the site's center, while Populus trees will dominate the landscape along the southern boundaries and areas near the landfill, forming a barrier to block contaminants emitted into the air. Due to their capacity and growth conditions, Miscanthus grasses will be planted in lower-lying areas and lagoons prone to flooding or waterlogging during the rainy season, where they can capture contaminants carried by surface water. The seven bioremediation strategies will be developed through a combination of Populus trees, Miscanthus grasses, and industrial hemp, resulting in distinctive landscapes that address contaminants at both surface and subsurface soil levels (Figure 3.).

Using energy crops, the brownfield can be transformed into an agricultural landscape that includes agroforestry, hemp fields, and grass fields of *Miscanthus* spp. The fields can start to diversify through natural vegetation succession, cultivation operation, and raw material production (Figure 3). Furthermore, the energy crops require labor for cultivation, thereby increasing local employment. In this process, the cultivation activities can be part of the social engagement program and the tourism experience program that allows local community members and visitors to participate in the harvesting process. Eventually, as the energy crops reclaim the site, they also prepare the site to adapt to the local community and boost Radford's economic development.

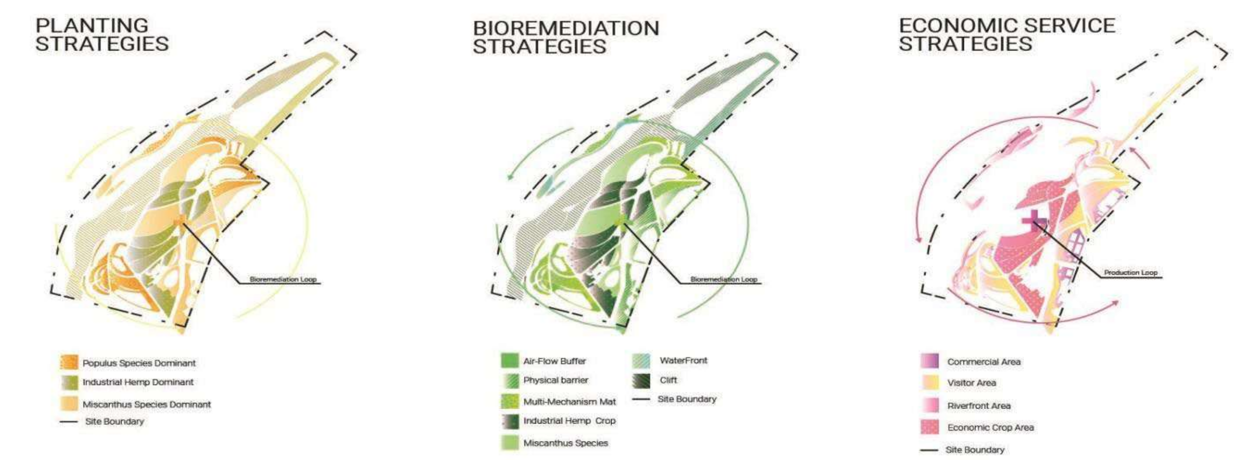

Figure 3. The NNRE Strategy Implementation in Radford Former Foundry. Diagram by the authors.

3.2 Landscape agents – phytoremediation

Phytoremediation is a simple, low-cost, and economical method to reclaim post-industrial brownfields, but different contaminants require different plant species for phytoremediation. Due to the NNRE framework of multifunctionality in facilitating services, the selected plants can be categorized into three groups, namely energy crops, spontaneous invasive plants, and ornamental plants. All these should exhibit significant phytoremediation properties and be low maintenance and self-sufficient. The chosen species will be planted around the site to form a reclaiming landscape with functioning ecological, social, and economic services.

Industrial hemp: Industrial hemp (Cannabis sativa L.) is a feasible, sustainable, and economic landscape agent for the phytoremediation of the Radford Foundry site. Industrial hemp is best grown at temperatures of between 16 and 27°C and requires sunlight of between 12 and 14 hours (McPartland et al., 2004; Nath, 2022). It requires minimal nutrient input and irrigation so it can readily adapt to different soil conditions and grow in different climate zones. This high tolerance makes it suitable for planting in closed landfills and heavy metal-saturated soil. Furthermore, industrial hemp is a fast-growing plant that takes about 10 to 16 weeks to become mature and ready to be harvested for fiber (Cherney & Small, 2016; McPartland et al., 2004)

In the phytoremediation process, industrial hemp efficiently took up heavy metals (i.e., Cr, Zn, Cu, Se, Cd, Ni) (McPartland et al., 2004). It also can degrade organic compounds in irrigated soil (Placido & Lee, 2022). Specifically, industrial hemp promotes contaminant-degrading enzymes by exuding allelopathic chemicals for the contaminants found in the site: Naphthalene, Benzo(b)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene (Placido & Lee, 2022). Moreover, industrial hemp planting will enhance the bacterial degradation of Benzo(a)pyrene and Chrysense (Placido & Lee, 2022). The fiber of industrial hemp can function as a biosorbent to accumulate cobalt.

Besides its phytoremediation properties, industrial hemp preserves soil nutrients. During the growing process, 10 tons of hemp crop will extract 90 kg nitrogen, 25 kg phosphate (P_2O_5), 90 kg potash (K_2O), 60 kg calcium, 10 kg magnesium, and 10 kg sulfur in one hectare (McPartland et al., 2004; Placido & Lee, 2022). These nutrients will return to the soil during field retting and water retting (McPartland et al., 2004; Placido & Lee, 2022). Therefore, industrial hemp is a low-maintenance plant that requires minimal fertilizer and can effectively contribute to brownfield reclamation in Radford.

Populus species: Populus species are native to North America and can adapt to different soil types and climate zones. Populus is a fast-growing species tolerating heavy metal-polluted soil and producing high biomass, which can be implemented in Radford Foundry to reclaim the land for public use (Pandey et al., 2016).It can act as a phytoextraction and photo-stabilizer that stabilizes polluted soil and prevents erosion while it can extract metallic and organic pollutants into plant tissue (Pidlisnyuk et al., 2014). Therefore, five populus species have been selected to form a phytoremediation landscape. These are *Populus deltoides*, *P. nigra, P. tremuloides, P. grandidatate,* and *P. balsamifera*. Populus acts as an excellent accumulator toward N and P at a significant level, as well as Cd, Cr, Cu, Pb, and Zn (Liu & Schnoor, 2008). Apart from its capability to accumulate heavy metal, Populous species with deep root systems can also take up persistent toxic PCBs to be stored in their woody stems and leaves. Furthermore, Populus can function as a carbon sequestrator to reduce CO_2 emissions, mitigating the impact of climate change (Pandey et al., 2016). Thus, this evidence indicates that Populus can help to remediate the complex contamination and environmental problems in Radford Foundry.

Invasive plants: Miscanthus species are rhizomatous, bamboo-like grasses that can grow in and tolerate different environments, from water-saturated wetlands to milling sites (McCalmont et al., 2017; Pandey et al., 2016). Although it is defined as an invasive plant in Virginia, its phytoremediation ability and biomass byproducts make it a good choice for the Radford Foundry reclamation, albeit on a limited scale. The four miscanthus species that have been selected for their capability for phytoremediation and economic significance are *Miscanthus sinensis, M. sacchariflorus, M. floridulus,* and *M. xgiganteus.* Miscanthus is a non-food crop so there is no risk of contamination entering the food web during phytoremediation (Pandey et al., 2016). Miscanthus is mainly used for photo-immobilization and phytoextraction applications in closed landfills to capture landfill leachate that takes up the organic compounds from soil to plant tissue and prevents the transport of contaminants in soil (Pidlisnyuk et al., 2014). Miscanthus can take up a small amount of heavy metals (i.e., As, Sn, Cd, Cr, Cu, Ni, Pb, Zn, and Al) (Pandey et al., 2016; Pidlisnyuk et al., 2014).

Furthermore, miscanthus can increase the organic matter in soil, boosting microbial activities and soil-living invertebrates. Capturing nutrients in groundwater through their rhizomes can help improve both surface water and groundwater quality (Pandey et al., 2016). All these properties of miscanthus can be implemented in contaminated spaces, such as closed landfills, waterlogged spots, and waterfront space, at the Radford Foundry site.

Landscape rotation: Crop rotation can benefit crop production and soil conditions, including soil fertility, soil erosion, and soil biology (Sumner, 2018). Forming a rotation system with selected crops can help achieve self-sufficiency and aesthetic value in the transformation park, although the period of the rotation system is dependent on the properties of the selected crops(Sumner, 2018). For example, Populus can be formed as a shore rotation woody crop (SRWC) system with eucalypts, poplar, and willow to function in bioremediation and provide an alternative revenue from timber production as well as raw material for bio-chemicals, paper, and plywood (Rockwood et al., 2004). In comparison, Industrial hemp can be matured within 60 days in the summer season, allowing rotation within a year. In Fumagalli's research, the research team highlighted the benefits of industrial hemp rotation with a winter crop, Lupinus albus, that the rotation can improve and recover the soil quality during the bioremediation process due to the increased soil concentration of live bacteria and bioavailable percentage metals (Fumagalli et al., 2014). Therefore, the rotation system and bioremediation capability indicate that winter cultivation crops in sequence with industrial hemp can increase soil quality in the short timescale, whilst woody crops can function as environmental mitigation during the relatively longer timescale rotation.

4 RESULT & DISCUSSION

4.1 Environmental benefits

The utilization of energy crops in Radford's former foundry brownfield reclamation can function with the landscape's multifunctionality in terms of the NNRE framework for transforming polluted sites into productive and environmentally sustainable landscapes. The energy crops, Cannabis sativa L. (industrial hemp), Miscanthus spp., and Populus spp. emerge as particularly viable options due to their unique characteristics and phytoremediation potential.

The phytoremediation mechanism in root systems of industrial hemp and miscanthus can help to store and degrade heavy metals and the persistent toxic PCBs can be extracted by Populus species. Besides, all of these selected crops can help to remove contaminants from the soil at Radford's former foundry site and eliminate toxic particles such as VOCs and SVOCs from the surrounding neighborhood and water features. Specifically, the exuding allelopathic chemicals from industrial hemp can degrade naphthalene, benzo(b)fluoranthene, benzo(a)pyrene, and dibenzo(a,h)anthracene (Placido & Lee, 2022). The phytoextraction and photo-stabilizer from Populus spp. can extract metallic and organic pollutants into plant tissue, stabilize polluted soil, and prevent erosion. Miscanthus will be implemented mainly to absorb landfill leachate based on its photo-immobilization and phytoextraction capability. It can take up organic compounds from soil to plant tissue and prevent contaminants from being transported into the soil (Pidlisnyuk et al., 2014). Furthermore, industrial hemp and miscanthus enhance soil health by increasing organic matter content, promoting microbial activity, and improving water quality through nutrient capture (Figure 4). The planned rotation system will enhance the effectiveness of brownfield reclamation, optimize soil fertility, minimize erosion, and promote sustainable crop production.

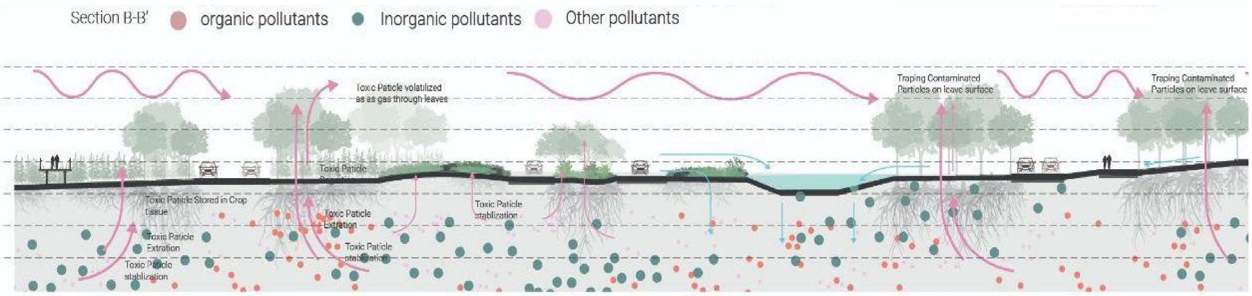

Figure 4. Phytoremediation process and pollution prevention. Diagram by the authors.

4.2 Community engagement by brownfield reclamation

The selected crop and rotation system can help to reclaim the contaminated field and ensure nutrient recycling on the site, while the cluster of plant species will form a unique landscape that can provide social service.

Social vitality can be strengthened by developing a new social program along with the park reclamation process. The first stage will mainly focus on removing and preventing contaminant emissions by planting fields and proposing light recreation, such as walking trails and resting pavilions. The next stage will entail opening the site to more intimate social programs, such as providing a picnic lawn, children's playground facility, or dog park, and eventually access to the water for boating or fishing in the lagoon.

The reclamation of brownfields can also raise public curiosity, and attract new visitors to the city, which will positively impact the community. According to Klenosky's research in Freshkill Park, the transformation of the brownfield can boost the number of visitors to Radford and the newly transformed site (Klenosky et al., 2017). Furthermore, the new proposed production field is combined with a planting field that distinguishes the landscape of the transformed brownfields from the urban green land in Radford. In addition, visitors can learn more about energy crops and their ability to help clean contamination with phytoremediation mechanisms to maintain the park's self-sufficiency. There will also be opportunities to participate in the harvest activities.

4.3 Local economic revitalization by brownfield reclamation

The selected energy crops can help generate an alternative revenue, which will not only increase surrounding property prices but also constitute an emerging new economic service for the city of Radford, especially associated with the increased global biodiesel and bioethanol market. The global biodiesel and bioethanol market is expected to reach 41.4 billion liters in 2025 (Rouhany & Montgomery, 2019). The trend is similar in the U.S. Market. In 2022, biodiesel and bioethanol production was about 3.1 billion gallons, and ethanol production was about 15.4 billion gallons, which indicates a huge demand in the U.S. market (Agriculture, 2024).

Industrial hemp, miscanthus, and poplar species are considered to be excellent feedstocks for biodiesel and bioethanol production due to the high levels of lignocellulose in *Miscanthus* spp., and cellulose, lignin, and hemicellulose in *Populus* spp. and industrial hemp (Pandey et al., 2016). Therefore, the yield from the selected plant species can be exported as raw material to foster a new economic service by reducing biodiesel and bioethanol imports or increasing exports to create new revenue for the local economy.

Furthermore, the hemp production report indicates that most people working in industrial hemp production are aged between 35 and 64 (USDA, 2022), and market expansion will increase employment opportunities. The industrial hemp field implemented in Radford can create new jobs. Thus, the multi-benefit of brownfield reclamation is shown in different dimensions, benefiting multiple stakeholders, including city administration. Benefits are likely to include increased city revenue, increased employment opportunities, and increased property values.

5 CONCLUSION

In conclusion, the former Radford Foundry transformation can benefit the city and the residents, and its transformation into an open park will help the city and the site adapt to further development in the new era. The limitations of Radford Foundry's transformation include planning difficulty, difficulty obtaining local financial support, social engagement, and compatibility with the city's future vision. Therefore, the design-based research adapts to the New Natural Resources Economic (NNRE) to address contamination on the site, which consists primarily of VOCs, SVOCs, PCBs, and inorganic materials. The literature review and case studies revealed that the selected crops can address the complex contaminant as well as provide a new social and economic service, namely, industrial hemp, Populus spp., and Miscanthus spp.

Industrial hemp emerges as a sustainable and economically viable solution for phytoremediation due to its adaptability to varied soil conditions, fast growth, and capacity to absorb heavy metals. This plant not only efficiently takes up contaminants like VOCs and SVOCs but also promotes the degradation of organic compounds. Moreover, its nutrient extraction process provides a means of returning valuable nutrients to the soil. Populus species, known for their adaptability and rapid growth, offer a unique set of advantages. With their deep root systems, these trees can act as phyto-extractors and stabilizers, effectively accumulating heavy metals and stabilizing polluted soil. Furthermore, they contribute to carbon sequestration, aiding in the mitigation of climate change impacts.

Despite being considered invasive, miscanthus proves valuable for phyto-immobilization and biomass production. Its ability to thrive in different environments and capture a range of heavy metals makes it a suitable candidate for the brownfield reclamation in Radford. Miscanthus enhances soil quality by increasing organic matter and promoting microbial activity. Additionally, the selected plants are second-generation biofuel crops that can provide biomass. These perennial plants can reduce maintenance every year, and the energy crop plantation can bring new employment to the local job market and create a revenue stream for Radford. The redevelopment of Radford foundry can transform this market penetration of biomass fuels, replacing transitional fuel usage and alleviating greenhouse gas emissions. Integrating these natural resources into the Radford brownfield revitalization addresses environmental contamination and provides economic opportunities.

Brownfield reclamation using energy crops can lead to self-sufficiency in the remediation process, providing benefits to residents, communities, and cities by reducing financial burdens associated with contaminant cleanup and future development. Moreover, incorporating energy crops into brownfield redevelopment under the NNRE concept offers the potential to bridge the gap between the city and university partnerships by creating new employment and entrepreneurial opportunities, thereby enhancing social and economic vitality. This research provides valuable insights for rural cities dominated by a single industry and experiencing economic stagnation, suggesting that natural resources can be leveraged for revitalization. Landscape architecture in this context requires strategic, cross-scale considerations to achieve multiple objectives. Thus, this study presents urban planners, designers, and landscape architects with a multifunctional approach based on NNRE, moving beyond simple brownfield design to enhance the physical environment within a broader recreational or cultural revitalization strategy.

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