Turning Heritage Railway Architecture into an Infrastructure for Resilience and Circularity: An Opportunity for Sustainable Urban Regeneration

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Turning heritage railway architecture into an infrastructure for resilience and circularity: an opportunity for sustainable urban regeneration

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Keywords: Abandoned railways, Repurposing of brownfields, Sustainable urban regeneration, City-nature hybridity, Circularity, Heritage adaptive reuse.

Abstract

Since the introduction of railway lines and train stations in the heart of industrial cities, they have constituted a scar in the urban fabric, opening up an often-complex dichotomy between the world of machines and the urban world, between trains and people. This scar has become even more apparent now that several railway infrastructures have fallen in disuse and are left to evolve into contemporary industrial ruins. Historic railway buildings and structures are an important subset of the urban architectural heritage to be enhanced. At the beginning of the 21st century, we started witnessing urban regeneration projects fully enhancing the potential of these abandoned infrastructures running through the heart of cities and already naturally harbouring biodiversity. With the "Viaduct Des Arts" in Paris and the New York "High Line" as precursors, several European cities are now embracing this approach. This paper looks at elevated rail tracks in urban settings and how their original monomodal scope can be reinterpreted through a strategic – sustainable, dynamic and open - approach enhancing their potential for power generation, food growing, biodiversity harvesting, and social interaction. After a comparative analysis of 5 case studies, the paper proposes a methodology for defining adaptive reuse design scenarios for disused elevated railways. As a result, such infrastructures become opportunities for sustainable urban regeneration to increase resilience, resource efficiency, and circularity.

1. Introduction. Railways and Urban Dichotomy

Since its creation, the railway station has been characterized by a dichotomy between the world of machines - composed of trains, noise, and restrictive rules – and the urban world, which belonged to people. (Fig. 1). From the Nineteenth century onwards, the city and rail domain [1 p. 92] were in need for an intermediation, a role often attributed to travel buildings as a continuation of the city. In his famous book "*Storia dei viaggi in ferrovia*" Wolfagang Schivelbusch explains how the double nature of the railway station can be interpreted as "part fabric" and *"*part palace"*;* and it introduced a real innovation in the history of architecture at that time [2 p. 186-187]. The analysis provided by Schivelbusch can be extended to other aspects of the railway system, such as elevated tracks and the underlying arches, which offer possibilities to reconnect the world of machines and that of city life.

Figure 1. The first railway in UK Liverpool – Manchester (Public Domain File: Opening Liverpool and Manchester Railway.jpg) Source: S.G. Hughes - T.T. Bury (1833 revised edition), Coloured Views on the Liverpool and Manchester Railway. London: Ackermann & Co; plate 8. This scan/photograph from a private collection, via the Bridgeman Art Library (STC 267569) and Artfinder.com (description page, image) https://en.wikipedia.org/wiki/Crown_Street_railway_station#/media/File:Railway_Office,_Liverpool,_from_Bury's_Liverpool_and_Manchester_Railway,_1831_-_artfinder_267569.jpg

URBAN DOMAIN/RAILWAY DOMAIN – Initially the urban railways were connected to the industrial area and not to the heart of the city. Observing some of the European capitals from the sky we can appreciate how the roads appear integrated and metabolized by the city, while the railway tracks and stations often seem to be neglected. The railway appears as a scar on the urban fabric, an urban threshold systematically

fenced in and not yet organically absorbed in the urban fabric and the city's life. Contemporary European Capitals attempted to solve this problem by moving the railway tracks to a different level, be that suspended or buried underground, in the attempt to generate a threshold space between the city and the railway. Many researchers frequently supported this argument during the past century, proposing an image of cities vertically subdivided into layers[1]. However there have always been limitations to the implementation of such strategies as they were not economically sustainable and justifiable.

The post-industrial cities and the new means of urban transportation introduced in the Twentieth century marked the end of several train lines across cities worldwide. After the interruption of their original function and the subsequent decay of the infrastructures, cities faced the dilemma of demolishing or preserving them. Considering demolition's enormous financial and environmental impact and the fact that they are part of our built heritage, the second option seemed the most viable. Some more recent projects (such as the emblematic case of the High Line in New York, opened in 2009) observe and speculate on the state of change after the interruption of the original function, drawing inspiration from the aesthetic appeal of industrial ruins and overgrown vegetation. Reusing material, spatial, and programmatic resources while giving them new life. On the one hand, this approach aims to preserve a memory of the original purpose; on the other, pandering to the natural evolution of the abandoned structures, it identifies the ecological and social potential that lies within the creative readaptation and reappropriation of existing structures.

Going back to Shivelbush's quote, we can gather that existing infrastructures need to be Reinvented, Re-created, and Re-interpreted, injecting a new "dichotomy" in their dialogue with the city. It entails establishing and provoking a new accident in the interrupted railway infrastructure, allowing us to break the mimicry with existing buildings and generate new design opportunities. [3 p. 34]

Historically railways are attempting to combine two different domains (City domain vs train domain). While doing so, they are accepting the challenges introduced by the new infrastructure as a momentum of reuse for new project opportunities. Bearing in mind the dual nature of the railway in architecture history, this paper projects the future of existing infrastructure in a sort of fantastic combination, answering the question, "What if..?" [4 pp. 8,44] "What if a railway behaves like a building?", and "What if a railway behaves like a linear park?". Respectively, the New York Highline and the Promenade plantée can easily be identified in these dichotomies.[2]

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[1] Harvey Wiley Corbett proposes a captivating idea of a layered city while discussing the challenges posed by New York traffic. He sees New York like a "Venezia Modernizzata" in which all the pedestrian levels are distributed in vertical, far from the water channel (Corbett's idea of the city is also mentioned in the book "Delirious New York" by Rem Koolhaas).

[2] There are several analogous experiments. Such projects propose a fantastic combination to better integrate the City domain and infrastructure domain. "What if a building behaves like a road?" Among other examples, we can cite Le Corbusier's project for Rio in 1929, proposing a freeway on top of a long building. The same is true for the Turin Lingotto by Matteo Trucco from 1923, a building with a car race track on the roof. Both examples show how the "What if" can revolutionize the approach to reuse and regeneration.

2. State of the art

In the Twentieth century, Architects and Designers, but also Artists, found a way to highlight and take inspiration from such lacerations of the urban fabric and the discontinuity generated by the interruption of the mono functionality/monomodality of the infrastructure. This condition led to a proliferation of possibilities to speculate on this criticality through initiatives aimed at reusing the abandoned infrastructures' resources (materials and spaces), celebrating historic craftsmanship and preserving the industrial heritage. The indisputable potential offered by the linear spatial configuration of such infrastructures and their location in the very heart of cities suggested that the reuse strategies should not be limited to immediate local programmatic strategies but rather be part of a broader vision and contribute to ecological and social wellbeing on an urban scale.

In this view, though often spontaneously and not legitimately, spaces beneath railway viaducts' arches were appropriated over time. Research focusing on London's Great Eastern Railway Company's viaduct [5 pp. 351-364], for example, retraces the history of such appropriation by the local community and encourages researchers "to look at the ways in which similar structures can be appropriated and subverted for uses for which they were not intended but which then become part of the life of a local community" [5]. This awareness should be seen as a starting point for any motivated heritage railways adaptive reuse project, aiming at preserving the site's identity while scaling up the positive effects on the surroundings and the whole city.

It is now commonly recognized that historic railway infrastructures and buildings are relevant examples of urban-built heritage, and even the decay of such structures, the rusted material remains, and the consequent appearance of insurgent nature that evolves outside of human intervention establishing a city/nature hybridity, have become aesthetically appealing to the urban population and the voyeuristic cameras of the tourists.

Initially, the main potential of such infrastructures lay solely in their capacity to become program generators and reactivate social interaction above and beyond the infrastructures themselves. However, considering a broader and more wholistic perspective, regeneration of such heritage carries the potential of mending the scar left behind by these linear infrastructures and transforming them into a fluid, pliant field able to absorb, transform, and exchange information with their surroundings, weaving biodiversity and renewable energy into the urban fabric and supporting new circular processes aimed at valorizing local resources. Favouring adaptive reuse must be seen not only as an aesthetic or functional practice but as an enhancement of existing spatial and material resources to activate the potential of these infrastructures to support circular processes of resource use, bringing together networks and areas of the city for resilience.

The benefits of reusing abandoned railways can influence all the different spheres of Sustainability: social, environmental and economic. It has been acknowledged in a recent study [6] that preserving such built heritage is not just a way of enhancing its cultural and architectural value or improving its urban context but rather a strategy responding to circularity principles. As an alternative approach to demolition, reuse

avoids turning the considerable volume of materials and energy embedded in the infrastructure into waste. Moreover, it increases the life expectancy of the built heritage. It creates opportunities for activating the local economy while revitalizing the context around it from an environmental, economic and social point of view (1 p. 21), in line with the circular economy goals.

In this view, a research project by ARUP called "Under the Viaduct: Neglected spaces no longer", recently investigated the potential linked with the activation - through design – of the often-marginalized spaces beneath elevated road and railway viaducts. By categorizing such infrastructure into four typologies, of which the wide variety of elevated railways represents the first, and by identifying four different occupation modalities ("Infill", "Landscape and public space", "Connectors", and "Adaptation"), this study highlighted the specific potential of Nineteenth Century railway arches, thanks to their spatial configuration and their versatility [7]. These features (spatial, aesthetic, constructive) also effectively support the evolution and progressive adaptation of uses over time, calling for a design approach that can foster modularity, flexibility and technological reversibility.

The same study underlines the adaptive reuse of railway viaducts' potential to mitigate climate change-related risks: "incorporating flood mitigation and anti-heat island effect climate resilience techniques into a structure's design" [7 p. 31] can turn these viaducts into infrastructures supporting urban resilience and climate adaptation.

To support the definition of a design approach oriented towards railway heritage preservation in line with sustainable urban regeneration, with a specific focus on circularity and resilience, our Research Group developed a methodology (Par. 3 of Methodology) and tested it in the research and design experimentations reported in this chapter. The comparative analysis of case studies and the different design investigations presented in the next section (Par. 4 of Methodology), demonstrate that "Adaptive strategies can infuse urban design" [8], and that adaptive reuse strategies can also impact the scale of the neighbourhood and the city at large, activating processes in line with the compelling need for climate adaptation & mitigation, and resources' preservation and circularity.

3. Methodology

To better understand the relevance and peculiarities of the industrial-built heritage subject, the research began by observing the historical evolution of the relationship between railway infrastructures - in European and UK cities in particular - from their introduction at the beginning of the Nineteenth Century until the present day.

The following step focused on identifying international case studies and best practices of heritage railway viaducts' adaptation and activation. The aim was to gather examples of different design approaches and strategies and map the environmental-technological solutions adopted. From a broader sample, five international best practices realized in a 30-year span (1993-2023) were selected to observe how heritage viaducts' reuse approaches have been developing. Following this phase, a comparative assessment of

the five case studies was performed through temporal, material, spatial, cultural, economic and ecological parameters. The results of these steps are reported in Par. 3.1.

These preliminary research activities led to the development of a methodology for evaluating and defining adaptive reuse design scenarios for disused elevated railways. By maximizing their potential, such infrastructures become opportunities for sustainable urban regeneration, promoting efficient and circular use of resources and increasing urban resilience. The proposed analysis and design methodology to approach railway viaducts' adaptation projects is based on the site's cultural, social and environmental value.

The methodology aims to maximize the potential of this particular type of heritage, enhancing its cultural and material identity to foster sustainable urban regeneration and ultimately transforming them into infrastructures that support the increase of resilience and the efficient and circular use of resources within the urban fabric.

The methodological approach is structured in the following ten interconnected phases, each one providing inputs and feedback applied to the following steps to favour a consistent approach at all the different scales (city, district, heritage site, infrastructure/building, component/material):

1. Context and industrial site historical analysis;
2. Urban scale analysis: anthropic, bio-physical and bioclimatic systems;
3. Analysis of current urban planning and regeneration plans and projects to develop specific approaches/proposals that can complement them by strengthening the role of the heritage railway from a cultural, functional and environmental point of view;
4. Kevin Lynch's analysis aimed at identifying the potential urban nodes to be connected through the adaptive reuse of the elevated railway;
5. Urban design to enhance the relationship between the infrastructure and the city;
6. Analysis at the building scale – current state, condition mapping, building materials, thermal performance, space syntax;
7. Meta-design at the "building"/infrastructure level to propose functions and spatial layouts aimed at adapting the elevated railway to new uses;
8. Environmental strategic design, aimed at using passive, active and ecological systems for a zero-energy/zero-carbon adaptive reuse;
9. Technological design, enhancing the materials and components of the built heritage through conservation and reuse;
10. Evaluation and validation of design solutions.

The methodology is structured on a multiscale and inter-disciplinary approach (between technological-environmental design and architectural design) that examines the relationship between the urban context and the railway infrastructure, studying the interactions between the latter and the urban fabric in the present and, at the same time, considering the railway's past role often strongly intertwined with the city's urban evolution and industrial activities.

In this sense, the design phase of the methodology aims to prefigure the role of the railway viaduct infrastructure, the object of strategic interventions aimed at enhancing its linear morphology, the spaces under the vaults, the spatial and perceptual relationship between the structure and the areas beside it, but also the material content itself, usually massive and consistent, may have in the more general strategy of urban regeneration. The goal is to reinvent the role of the infrastructure, mending the relationships interrupted by the suspension of its original function and activating new (efficient and circular) flows in the management of resources at the urban level, re-creating continuity in the ecological network, and contributing to energy production and consequent decarbonization.

3.1 Comparison of five international elevated railway adaptive reuse case studies

As highlighted before, a relevant aspect of the research methodology focused on case studies assessment. Below is a list of the case studies selected (Table 1), presented in chronological order to highlight a progressive evolution of the adaptive reuse strategies:

1. VIADUCT DES ARTS, 1993, by Patrick Berger & Janine Galiano, Paris, France.
2. "HIGH LINE" New York, 2003-2009, by James Corner Field Operations and Diller Scofidio + Renfro with Olafur Eliasson, Piet Oudolf landscape architect, and Buro Happold.
3. IM VIADUKT, 2004-2010, by EM2N I Mathias Müller | Daniel Niggli Architekten AG, Schweingruber Zulauf Landschaftsarchitekten, Zürich, Switzerland.
4. THE ARCHES PROJECT, 2019, by Boano Prišmontas, London, United Kingdom.
5. CAMDEN HIGHLINE, 2023-ongoing, by James Corner Field Operations with vPPR Architects, Piet Oudolf, Hew Locke, Street Space, Speirs, Major Tony Gee Engineering, AKT II, Rider Levett Bucknall, Atelier Ten, Pentagram, Authentic Futures, London, United Kingdom.

Once people acknowledged that abandoned industrial structures are relevant examples of urban-built heritage, the creative readaptation and reappropriation of elevated rail tracks in urban settings have been at the centre of the urban regeneration discourse. In the late Twentieth Century, we witnessed the construction of the "The world's first elevated park (first phase completed in 1994) and the first "green space" constructed on a viaduct". [9] [10]. The brick and stone viaduct connecting the Place de la Bastille to the eastern reaches of Paris was built in 1859 for the Paris-Strasbourg Railway Company. The suburban trains terminated their service on this track in the 1970s when newer long-distance routes were introduced. In 1993, the Promenade Plantée (French for tree-lined walkway), also known as the Coulée verte (French for green course), a 4.7 km elevated linear park, was built on top of the obsolete railway infrastructure. The parkway is articulated both vertically and horizontally, descending to street level, becoming a mall, running below street level and passing through several tunnels, expanding into gardens, splitting and terminating in the square Charles-Péguy. The green promenade has enclosed sections and open spaces with expansive views.

Table 1. Case study characteristics

CASE STUDY	Year	Length	Access to the elevated viaduct	Above arch program	Under arch program
Viaduct des Arts Paris 	1993	4.7 km (total) 1.5 km of arches	Stairs and ramps. The viaduct descends to the street level and becomes a mall and a park.	Elevated linear park	"Viaduct des Arts" artisan showrooms (violin-makers, glass blowers, jewellers, furniture and tapestry restorers)
High Line New York 	2003 - 2009	2.4 km	Stairs, ramps and elevators	Public linear park. Art installations, pop-up retail shops, fitness activities, and fashion shows	NP.
Im Viadukt Zurich 	2004 - 2010	Approx 0.5 km	Stairs and ramps inside the arches	Bike path and pedestrian walkway	Ateliers, dance club, cafés, co-working spaces, culture and event spaces, market, restaurants, retail spaces, youth church, fitness studio, training hall, workshop spaces
The Arches Project London 	2019	NA.	NA.	Railway	Retail activities and productive spaces (studios, laboratories, workshops, mechanics, shops, micro-breweries, co-working spaces)
Camden Highline London 	2023	1.2 km	Stairs, slow stairs, balcony stairs, ramps, and elevators	Public linear park, children's play zone, volunteer-run allotments, and outdoor classrooms	Café kiosks, distribution stairs and ramps

The next stage was to covert the old vaults beneath the rail line at the western Bastille end of the parkway and running parallel to the avenue Daumesnil into exhibition spaces and, ultimately, into a series of artisans' workshops and galleries, transforming the viaduct in a major centre for the arts and crafts. In the Viaduct Des Arts[3] , we can find artisan showrooms ranging from violin-makers to glass blowers, jewellers, fashion and accessory designers, furniture and tapestry restorers, and lighting manufacturers. The intervention under the arches resulted from a unitary project, with the same treatment of the facades under the arches. The functional program was defined to preserve and promote local traditional artisanal crafts "that the long-haul freight networks destroyed a century earlier" [11]. In 2004, the Paris City Council transferred the Viaduct des Arts ownership to the Semaest[4] for 18 years.

The outstanding social and environmental benefits of such intervention did not go unnoticed, and the NY High Line competition and project followed 15 years later. This time the project did not invest the space under the rail infrastructure. Most of the attention revolved around the potential of biodiversity and the wild beauty spontaneously established in post-industrial ruin. The High Line winning project, by James Corner Field Operations and Piet Oudolf, is a 2.4 Km long public park built on an abandoned elevated railroad stretching from the Meatpacking District to the Hudson Rail Yards in Manhattan. The park interprets its industrial inheritance and reclaims a once vital portion of urban infrastructure. It translates the biodiversity that took root "after it fell into ruin in a string of site-specific urban microclimates along the stretch of railway, including sunny, shady, wet, dry, windy, and sheltered spaces". [12]

The long period of abandonment left room for wild grasses and flowers to grow undisturbed. The famous photographs made by artist Joel Sterfeld of the wild vegetation taking over the post-industrial structure once the trains had stopped running[5]served as an inspiration for the project developed by the winning team, who re-created aesthetic aspects to spontaneous vegetation in their proposal, producing a "distinctive kind of ecological simulacrum of what occurred on the derelict structure before its extensive landscaping". According to Gandy, in the project "wasteland as artifice" becomes appealing thanks to the appearance of the natural environment's agency. "The park, in this context, is a designed fragment of nature that inscribes social and political power into the urban landscape." [13 p. 1306] Kevin Loughran also refers to this project to show an example of what he defines as a "city-nature imbrication", which can also be identified in vacant lots where a decaying built environment and "insurgent" nature are aesthetically united. "Imbricated spaces present "city" and "nature" as active agents in their creation through the decay of the built environment and the growth of the natural environment". According to Loughran, spaces like the High Line demonstrate how

[3] https://www.leviaducdesarts.com/en/the-viaduc-des-arts

[4] The Semaest, a "semi-public company of the City of Paris, takes action on a daily basis to promote a new, local economy. Its aim: to preserve trade and handicrafts, to encourage the setting up of innovative, ethical and sustainable activities, and to improve the quality of life in neighbourhoods". http://www.semaest.fr

[5] For more on the photographic work of Joel Sternfeld and the way they influenced the aesthetic politics of the accidental landscape of the site before renovation, see (2 p. 2329).

“city-nature hybridity is a process existing outside of human intervention and suggests that city and nature can be the creators of an aesthetically interesting space.” [14 p. 321]

The paving system consists of modular pre-cast concrete planks with open joints, which welcome the growth of wild grass, similar to the growth of spontaneous vegetation through cracks in the city sidewalks. The park accommodates wild vegetation cultivated plants and alternates social and intimate spaces. The NY Highline is an example of a landscape that promotes biodiversity and acts as a catalyst for public life and real estate development.

Even though most of the urban railway infrastructure adaptive reuse projects are predominantly linear, following the direction imposed by the original infrastructure, their intent is to project and reconnect different parts of the city through physical, visual and natural (biodiversity) connections along the elevated infrastructure. Moreover, both projects transform the access points as opportunities to establish a dialogue with the surrounding city, stretching above and below the elevated viaducts. The NY High Line Access points are “durational experiences” designed to prolong the transition from the frenetic pace of city streets to the slow landscape above. In the Promenade Plantée, the parkway descends to street level, becoming a mall, running below street level and passing through several tunnels, expanding into gardens (Jardin de Reuilly and Jardin de la gare de Reuilly), splitting and terminating in the square Charles-Péguy. Also, in the upcoming project for the London Camden Highline project (scheduled to start construction in 2024) again by James Corner Field Operations (with vPPR Architects, Piet Oudolf, Hew Locke, Street Space, Speirs, Major Tony Gee Engineering, AKT II, Rider Levett Bucknall, Atelier Ten, Pentagram, Authentic Futures), the crossings under the arches, the vertical connections and access points to the park are described as “dramatic stairs & thresholds”, key elements of the project contributing to the spectacle of the scene. They acquire different connotations and expand their purpose and functionality, becoming vertical promenades, panoramic platforms and performing stages (slow stair, wraparound stair, balcony stair, transparent scenic lift). [15]

The project IM VIADUKT - Refurbishment Viaduct Arches by EM2N, in collaboration with Landscape Architecture Studio Vulkan Landschaftsarchitektur, began in 2004 as an architectural design competition, and it offers another example of repurposing urban rail infrastructures and transforming them into “unifying elements, converting the space under historic structures into usable cultural and commercial attractions”. The viaduct in question was originally built to support the city’s early Zurich rail lines from the Nineteenth century. Still, it acted as a massive separation between the urban part of Zurich and the city centre. “This reprogramming of the viaduct initiated two decisive urban impulses: the barrier became a linking structure, and the outdoor spaces around it were upgraded”. “The viaduct becomes a large-scale connecting machine and a linear building”, linked to the existing pedestrian and bike path, “to form a linear park that will be part of a culture, work and leisure mile”. [16]

The symbolic link between the two areas of the city proposed by EM2N is further underlined by one of the project's key features. As two railway viaducts running parallel on two different levels converge, taking advantage of the opportunity offered by the interstice generated by the infrastructural interchange, a new program (market hall) is

introduced under a covered space that receives natural light from bubble windows placed on the roof. The spaces under the old arches house ateliers, dance clubs, cafés, co-working spaces, culture and event spaces, restaurants, retail spaces, youth church, fitness studio, training hall, and workshop spaces. The intent was to attract tenants compatible with the district and rooted within the region, to let them design the interiors themselves or choose from a kit of elements.

Compared to the Promenade Plantée, and the IM VIADUKT, the Camden Highline project (Fig. 2) only assigned marginal and secondary functions to the viaduct arches, with pop-up cafes, new vertical connections, and crossings. Still, it's investing in another key potential aspect of adaptive reuse infrastructure. The elevated park aims to "knit together" the neighbourhoods around and reflect its social and ecological character. "Each section of the Highline will differ in character in direct response to the different neighbourhoods, contexts, and conditions through which it travels to give a true reflection of Camden's unique identity". A series of distinct ecosystems and experiences (woodlands, productive gardens, meadows and ancient British hedgerows) will increase the site's ecological value and boost Camden's biodiversity. [15] [17].

Lastly, the scale of influence of the Camden Highline project is worth noting, as it feeds into a broader, overarching public realm strategy, the Camden Green Loop. This comprehensive urban design strategy, launched by Camden Town Unlimited and Euston Town, will link landmarks, green spaces and cultural buildings through an integrated system of pedestrian and cycling routes between Camden, Euston and Kings Cross.

Figure 2. Camden Highline, London. Source: Camden Highline ©vPPR-JCFO

A different approach, more centred on Sustainability and circularity, is the "Arch Challenge competition" launched by Meanwhile Space[6] in London in 2017 to find a "kit of parts" solution which would challenge the standard Network Rail costs to carry out the basic internal lining of the arches' vaults. The enterprise recognized that the railway arches are the backbone of "productive London" and thought of a way to create affordable workspaces for local businesses and startups quickly - the competition brief aimed to develop a kit of parts that can be easily assembled and eventually redeployed. The temporary freestanding structures assembled with this kit of parts would improve the thermal quality of the space under the vaults to make it watertight and safe with a small budget. Moreover, to allow the capital investment required for a *meanwhile* use to be reused in many subsequent arches or similar spaces, the structures needed to be fully demountable and reusable, making the project less impacting and prolonging the life of the materials sourced and employed indefinitely. The competition was won in 2019 by Boano Prišmontas with THE ARCHES PROJECT (Fig. 3), consisting of a digitally fabricated structural system composed of 2 Modular CNC-cut birch plywood units that are repeated to infill the space under the arches as much as possible and stacked on walls to support the beams as well as the external polycarbonate cladding. Insulation is clipped on the CNC-cut plywood supporting beams. Each structural piece is also geometrically efficient when cut with a CNC machine, guaranteeing minimal material waste. The project's value lies in its nomadic, temporary and sustainable approach.

[6] "Meanwhile Space is the pioneering social enterprise at the forefront of Meanwhile uses, by bringing temporarily redundant space into productive use." (https://www.meanwhilespace.com/about)

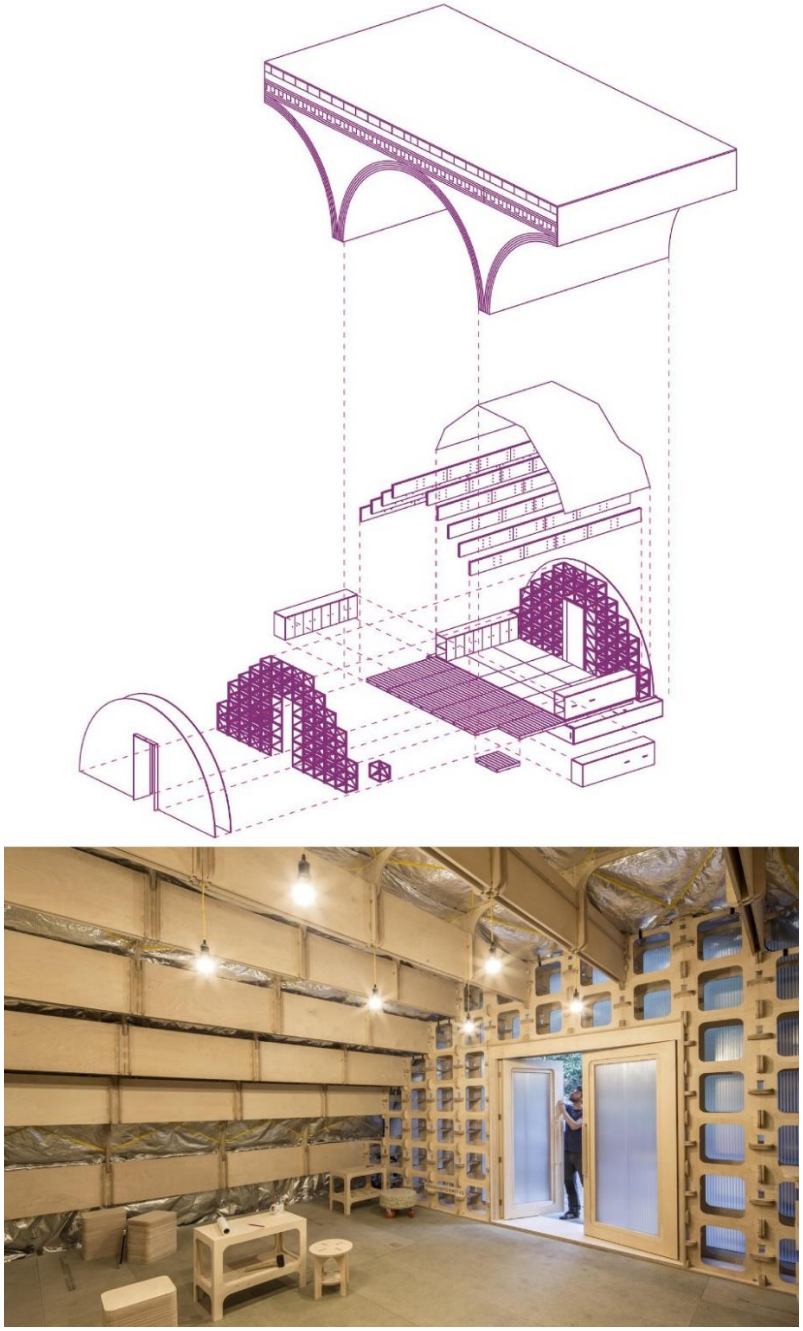

Figure 3. The Arches Project, London. Source: Image by Boano Prišmontas

To evaluate and compare adaptive reuse projects in terms of Sustainability and potential for circularity, the selected case studies have been assessed according to temporal, material, spatial, cultural, economic and ecological dimensions and features (Table 2):

- Temporal parameters of the project,
- Scale of influence,
- Economic implications,
- Social implications,
- Ecological benefits,
- Materials sourcing (dismantling, cleaning, storing building components for reuse).

Table 2. Case study comparative parameters

CASE STUDY	**Temporal parameters**	**Scale of influence**	**Economic implications**	**Social implications**	**Ecological benefits**	**Material sourcing**
Viaduct des Arts Paris	Concluded	Local. Connecting specific points of the city and linking malls and parks	SEMAEST-private-public consortium for infrastructure development	Increased property values and reconfiguration of the residential landscape. revaluation of private property value	Biodiversity and increased permeable surface for water management	NP.
High Line New York	Ongoing "Connections project" to connect the High Line to other key locations in NYC.	Urban. Reaching out. But controlled access and opening hours.	High Line non-profit, the City of New York	Increased local real estate values; 2 billion dollars in new economic activity throughout the district	Biodiversity Plants are native species, and some produced by local growers	Reusing materials. Materials sourced from within a 100-mile radius. Integration of old rail tracks in the landscaping
Im Viadukt Zurich	Concluded	Urban. Spatial barrier becomes a linking structure, and the outdoor spaces bordering it are upgraded	Funded by non-profit foundation PWG (invested in maintaining affordable residential and commercial rents in the city of Zurich)	Viaduct filled with tenants compatible with the district and rooted within the region. Planned as a meeting place for citizens of the district and its visitors	NP	Old stone walls remain in the space, and the viaduct remains untouched
The Arches Project London	Temporary & reusable	Local. Responding to the immediate context	Meanwhile Space, Lambeth Council, Mayor of London. Temporary use - capital investment can be reused.	Creation of affordable workspace for local businesses and startups	No pollution, energy saving due to better insulation and good natural light levels	Certified birch plywood sheets CNC cut to minimize material waste. Some design pieces make use of the offcuts and the plywood dust resulting from the CNC

						process, also used as a material substrate to create boards of bio-plastic material (mycelium)
Camden Highline London	Underway. Part of an overarching public realm strategy, the Camden Green Loop.	Urban. Connecting Camden Town with King's Cross, knitting together neighbourhoods around them.	Non-profit Organizations: Camden Town Unlimited, Euston Town, Camden Collective and the Camden Highline.	"Community making" events and hands-on engagement.116 new long-term jobs.	Biodiversity, Emergent plantings mixed with horticultural plantings, birch woodland, hawthorn hedge, perennial garden, rainwater garden, flowering meadow, hanging vines, butterfly garden, pollinators, Birds, insects, and bats	Repurposed aggregates and found objects. Circular understanding of materials and construction methods

Whilst the above projects are usually proposing linear parks on the elevated tracks, depots or small makers workshops under the arches, there is much more to explore in the potential of transforming these spaces into flexible infrastructures, structurally capable of significant adaptation in response to the evolving needs of cities and the climate emergency. In this regard, a significantly more holistic approach was adopted by the Low Line Partnership[7], which in 2021 developed a Strategic Vision for the Low Line Commons in London [18]. Promoting shared actions delivered by a range of different stakeholders[8], they saw the viaduct as a common and unifying element across the areas of Bankside, London Bridge and Bermondsey. The project adopts a holistic approach that employs strategic thinking in terms of infrastructure, funding, phasing, rehabilitation, and regenerative development. They foresee a set of different scale interventions that will tie these areas together into a coherent whole while celebrating each area's diversity and unique characteristics. To holistically address a multiscale vision, they propose a "toolkit, that can be applied at different scales of each space and in response to the character of each area and the local needs" aimed at enhancing access, connectivity, and public spaces, establishing biodiversity & ecological connectivity, building a climate resilient city, as well as improving economic prosperity through repurposing underused or empty arches. The value of this ongoing project lies in the multiscale approach combining site-specific, small-scale interventions along the areas crossed by the viaduct whilst guaranteeing a joint and unitary project. It means that the

[7] "The Low Line was coined by Southwark resident David Stephens. The concept has developed through a group of initial partners including Better Bankside, Blue Bermondsey, Borough Market, Team London Bridge, The Arch Company, and Southwark Council, who are steering the initial scoping, planning and communication of the project". (https://lowline.london/)

[8] Residents, Friends of Low Line, Business Groups, the Southwark Council, Arch Company, Landowners and developers and Network Rail).

infrastructure can potentially produce renewable energy, facilitate water management, contribute to climate mitigation and reintroduce biodiversity. Moreover, all these services can be introduced in a circular optic.

With the goal of investigating the potential of heritage railways within the urban environment, the research activities and design experimentations reported in this contribution have been developed at “Sapienza” University (Italy) in collaboration with Sheffield Hallam University (UK) and at Manchester School of Architecture (UK).

The following paragraphs describe the methodological approach developed by the Research Group to support design experimentation and illustrate its implementation on Mayfield, an important dismissed industrial site in Manchester currently undergoing a complex urban regeneration intervention, where the abandoned elevated railway plays a crucial role.

4. Results: implementation of the methodology on the Mayfield in Manchester (UK) case study

This paragraph presents the case study of Mayfield, a former textile industrial site in Manchester, which has been investigated within research activities and design experimentations by the Research Group. Below, after presenting the Mayfield site and its history (Par. 4.1), four different design experimentations are presented (Par. 4.2 and 4.3), implementing the above-mentioned methodology.

4.1 Mayfield Site: the role of heritage railway within a larger urban regeneration project

Manchester was both the first shock city of the Industrial Revolution in the 1700s-1800s and one of the most affected by post-industrial inner-city wastelands, with Mayfield being one of the leading examples of areas with great potential for regeneration.

Mayfield is a post-industrial wasteland in the heart of Manchester city centre, one of the most significant in the UK. It is adjacent to Piccadilly train station, Manchester's central train station. The railway viaducts to the north and the Mancunian Way to the south, act as physical barriers, isolating the area from the rest of the city centre.

The story of Mayfield began in 1782, when Thomas Hoyle established the print work for clothes in this former rural district, also thanks to the presence of the Medlock River, which has always strongly influenced the area. The site is prone to river flooding, recorded as early as Mayfield's first industrial phase in 1872. Nevertheless, the river Medlock also represents a crucial resource for the site, with the baths built in the 1850s in Mayfield to provide public washing, bathing and laundry facilities, and in later years, swimming pools for the labouring classes. At the end of the Nineteenth Century, the Thomas Hoyle & Sons factory shut down, while the Baths remained until 1947, when they were entirely demolished after being severely damaged in World War Two.

After demolitions cleared the ground in the early Twentieth Century, the new Mayfield train station – with its elevated viaduct and Arches - was built alongside Manchester London Road station (later named Piccadilly) to avoid over-crowding. The station was in operation till 1960, when it was closed to passengers and turned into a depot, till the complete closure in 1986. After the decommissioning, Mayfield station was used occasionally for events. At the same time, the arches under the railway were transformed into storage spaces through light interventions to close the "façade" of the vaulted rooms.

Today, the Mayfield site is known for the vast £1bn development with multifunctional buildings and a recently concluded park. In 2022, Mayfield Park (designed by Studio Egret West) was opened on the Southern part of the site. But the way the area is being developed, it is at risk of being not only walled-in but walling-out the rest of the city. This case study was selected by the Research Group because of the site's very complex and rich railway heritage (Fig. 4), characterized by the underused railway arches along Temperance and Amory streets, that show – on the contrary - a high potential for becoming a connecting element within the city. In fact, Mayfield's undergoing urban regeneration process represents an opportunity for proposing new specific plug-in design strategies to valorize the role of the industrial heritage in the site and within Manchester.

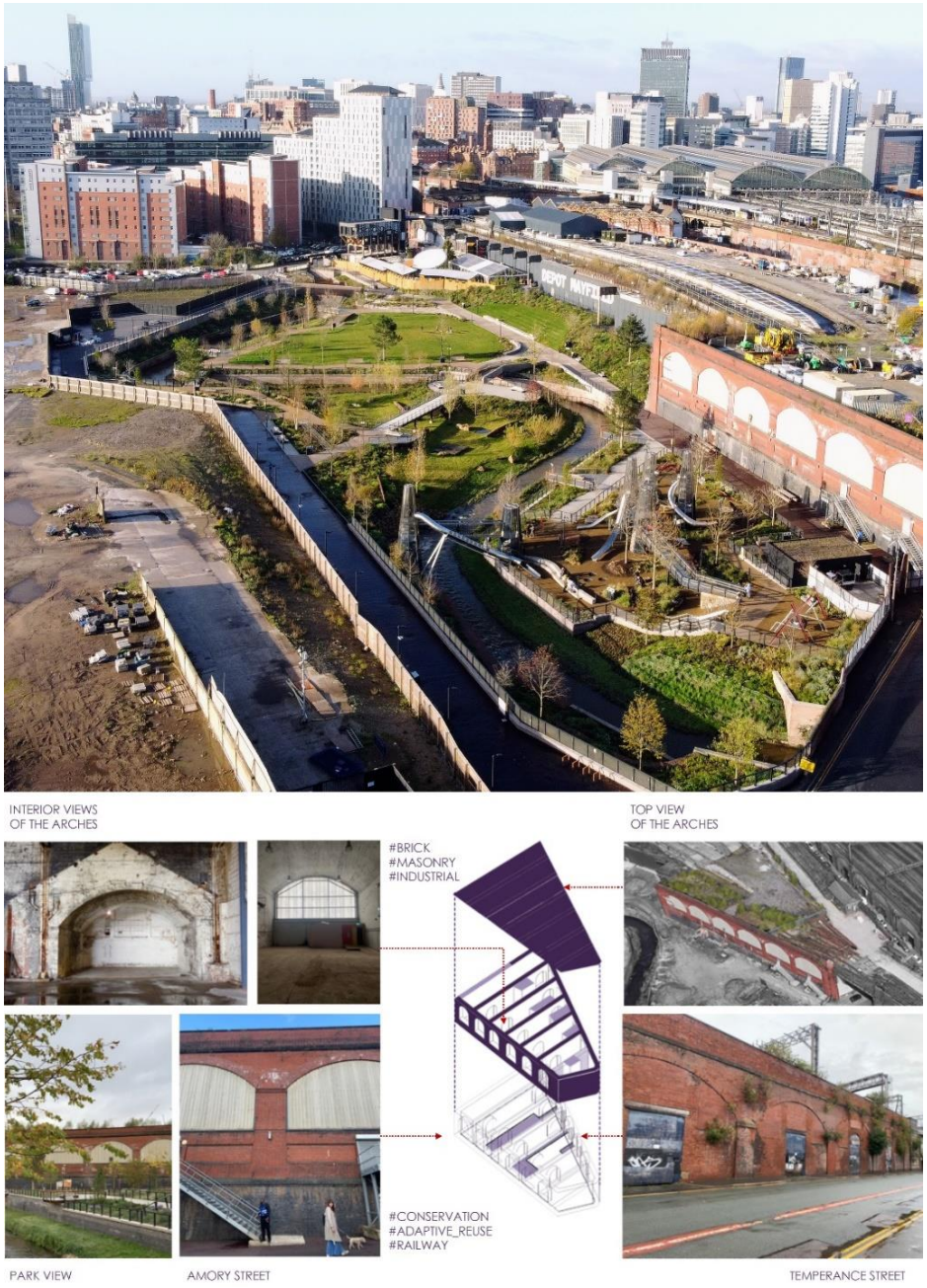

Figure 4. The Arches within the Mayfield site in Manchester. Credits: P. Altamura, L. Pedata, M. El Masri, F. Giani, S. Hamza, 2023.

4.2 Mayfield's Arches: from depot to Hub for Circularity and urban resilience

The first design experiment on Mayfield is based on the different and multiple steps of analysis described before in the research methodology. In particular, the potential role of the site with respect to the urban fabric was analyzed, highlighting how the current planning forecasts risk making the area a pole isolated from the rest of the city and clarifying how the role of the elevated railway along Armory and Temperance streets is precisely that of a margin between Mayfield and the rest of the city. For this reason, the design experimentations focused on the potential solutions to turn the dismissed infrastructure into an element of physical, functional, and cultural connection between Mayfield and the city of Manchester.

From the analysis of the recent history of Mayfield and of the current masterplan for the site, it became evident how the industrial heritage of the area has been marginalized in time. The heritage railway infrastructure, instead, is the only surviving built heritage on Mayfield, and the project tries to enhance its value as an identity element for the city.

Considering also the results of the environmental analysis on the site, as well as other context issues, the general objectives for the urban regeneration intervention were defined:

- To reconnect Mayfield to the city by enhancing the role of the heritage viaduct of the Arches;
- To contribute to an urban circular metabolism, considering different flows of material and immaterial resources;
- To re-integrate the river in the fabric as an ecological network/ identity element/ natural cultural heritage;
- To improve urban resilience in extreme climate events flood, by connecting the green/blue network;
- To enhance green areas and the connection of the different levels to the river to accommodate public functions;
- To improve community engagement and raise awareness on circularity and sustainability issues;
- To integrate new green areas and surfaces to improve biodiversity and air quality
- To produce renewable energy with integrated solutions, and ensure energy efficiency by valorizing the existing railways brick massive structure and introducing passive solutions.

The project's main innovations regarding the adopted Masterplan for the Arches are focused on the functional program and the use of the elevated infrastructure spaces. In particular, the old vaults beneath the rail line from its current use as a depot to a hub for circularity (Fig. 5) centred on three flows of resources:

1) *food*, with indoor hydroponic cultivation in the vaulted rooms of the Arches and a large greenhouse located on the former elevated railway surface;
2) *water*, enhancing the site's relationship with the river, promoting and implementing a circular and sustainable use of this resource;

3) *textile waste*, taking over Mayfield's industrial identity and offering the city a textile waste recycling hub for material and energy recovery.

Three sub-hubs are proposed to support a circular management of these flows of resources: an *urban farming hub*; a *living with the water community hub*; and a *textile recycling hub*.

A local food value chain is supported by two main spaces: beneath the two deepest vaults of Arches, there is a hydroponic plant nursery with a series of service spaces, including a market and a bar facing Mayfield Park; over the viaduct; the project changes radically the approach proposed by the Mayfield Masterplan – which foresees the construction of a multi-storey office building with a small portion of green roof – by designing a very large greenhouse with a mixed-use (food harvesting and restaurant) (Fig. 6). The water cycle inspires the project of the two central bays of the Arches, where educational and awareness raising activities on sustainable water management are hosted in flexible spaces that open up to the local community offering co-working, meeting and multipurpose spaces. Thirdly, the *textile recycling hub* provides a circular systemic solution by allowing the textile waste collected in the city to be recovered with a pyrolysis machine producing energy and recycled fibres.

The multiple and integrated environmental strategies and solutions (Fig. 7) adopted in the project include:

- integrated façade with vertical green and algae panels for biomass production and CO_2 subtraction in the south façade towards Mayfield Park, and moss "wall" on the north façade;
- green roof on the former elevated railway, mixed with water collecting/BIPV (building integrated photovoltaic) surfaces;
- a closed loop system for rainwater collection, filtering, storing and reuse for harvesting;
- energy production with multiple sources and primary production from BIPV in the form of LSC (luminescent) glazing composing the envelope of the greenhouse;
- use of natural light in the vaulted spaces enhanced by the installation of combined daylight reflecting/stack ventilation tubes that cross the thick layer of the viaduct floor;
- use of natural ventilation and thermal regulation exploiting the massive brick structure of the viaduct.

The connection between the Mayfield Park level and the elevated surface with the greenhouse and green roof is ensured by an outdoor staircase, highlighting once more how there can be effective design strategies to mend the scar constituted by the abandoned viaduct. Therefore, the viaduct's elevated surface becomes a support for energy production, food harvesting, vegetation growing, and water collection, offering at the same time technical spaces and plenty of room for social gathering and promoting a circular and sustainable approach to urban regeneration in the city of Manchester.

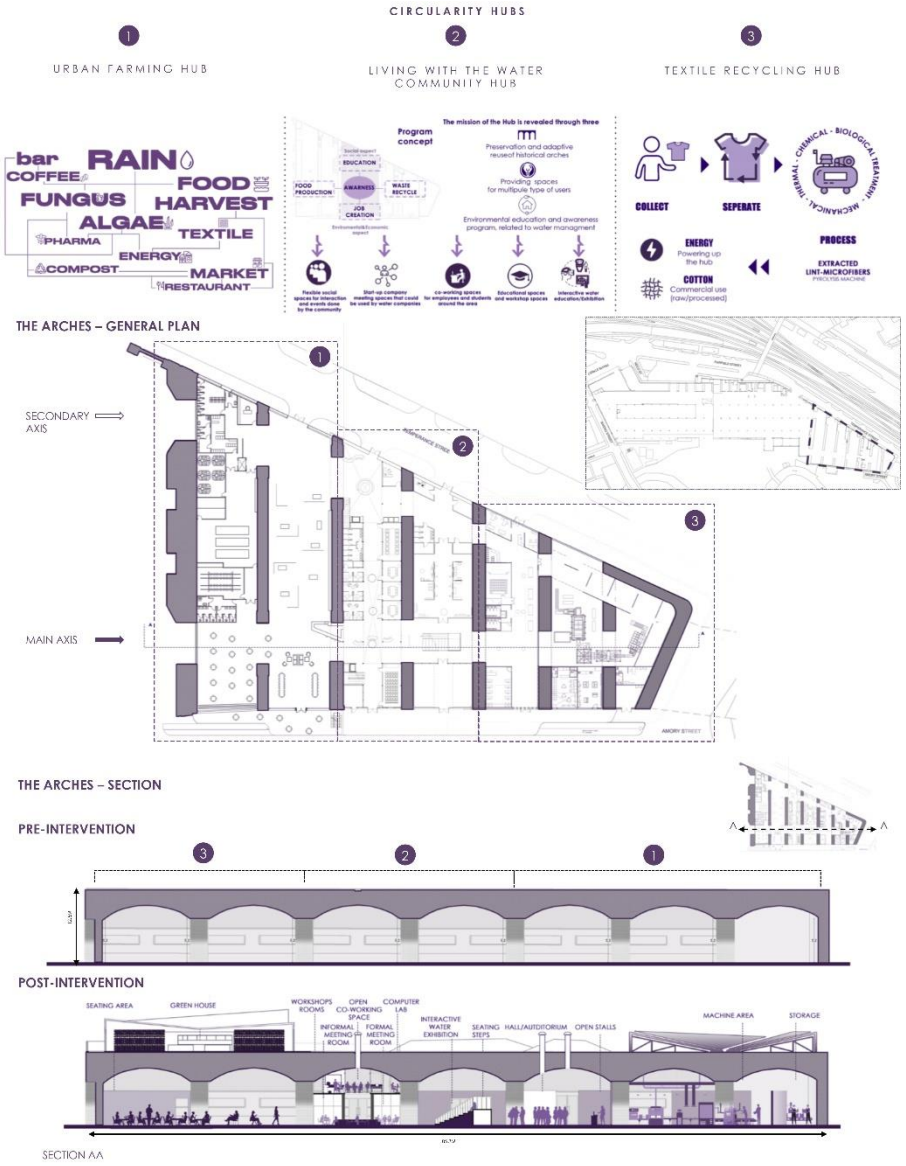

Figure 5. Mayfield Arches as Circularity Hubs supporting closed-loop and sustainable value chains for food, water and textile waste. Credits: P. Altamura, L. Pedata, M. El Masri, F. Giani, S. Hamza, 2023.

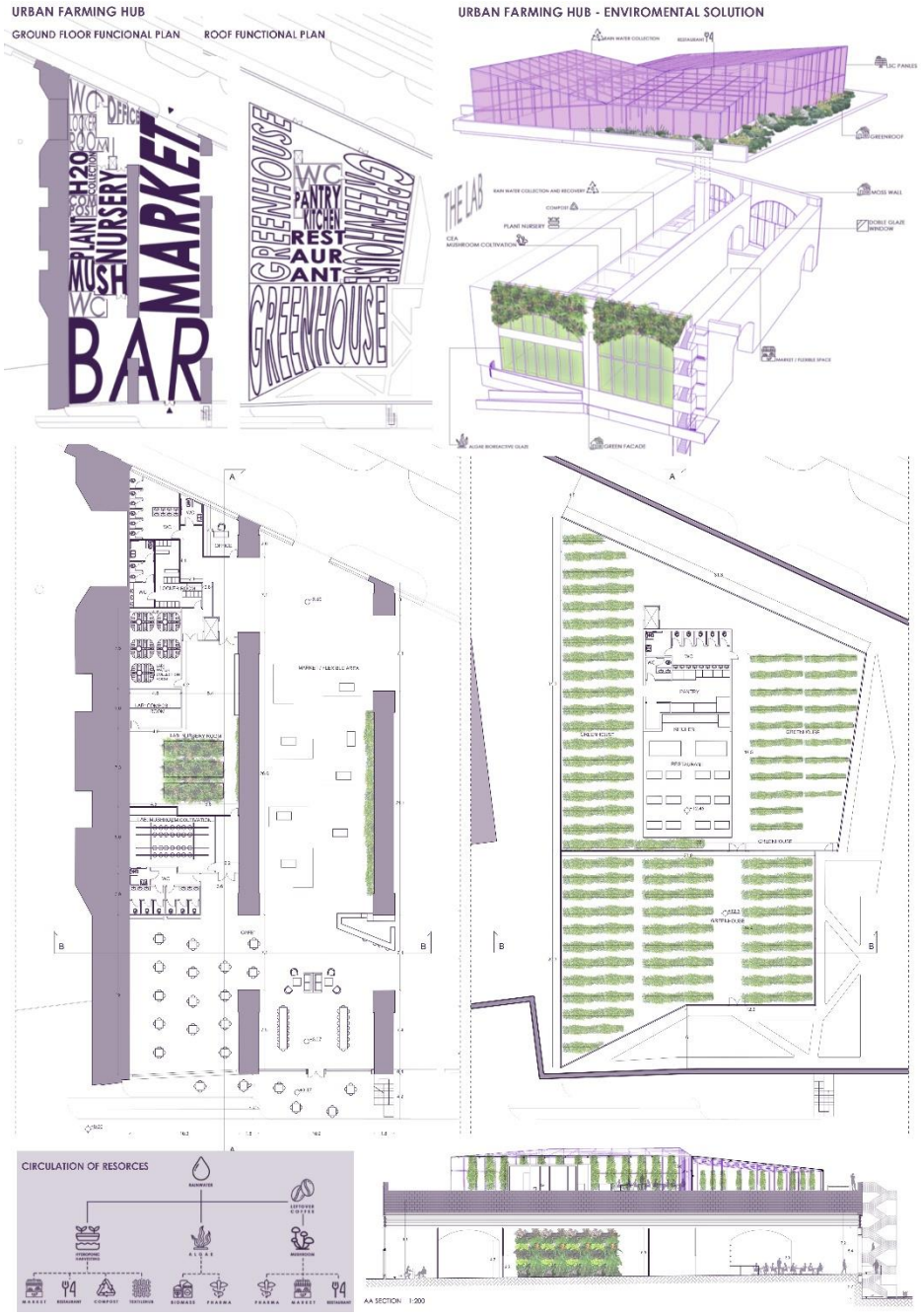

Figure 6. Mayfield Arches environmental technological design strategies and detailed solutions. Credits: P. Altamura, L. Pedata, M. El Masri, F. Giani, S. Hamza, 2023.

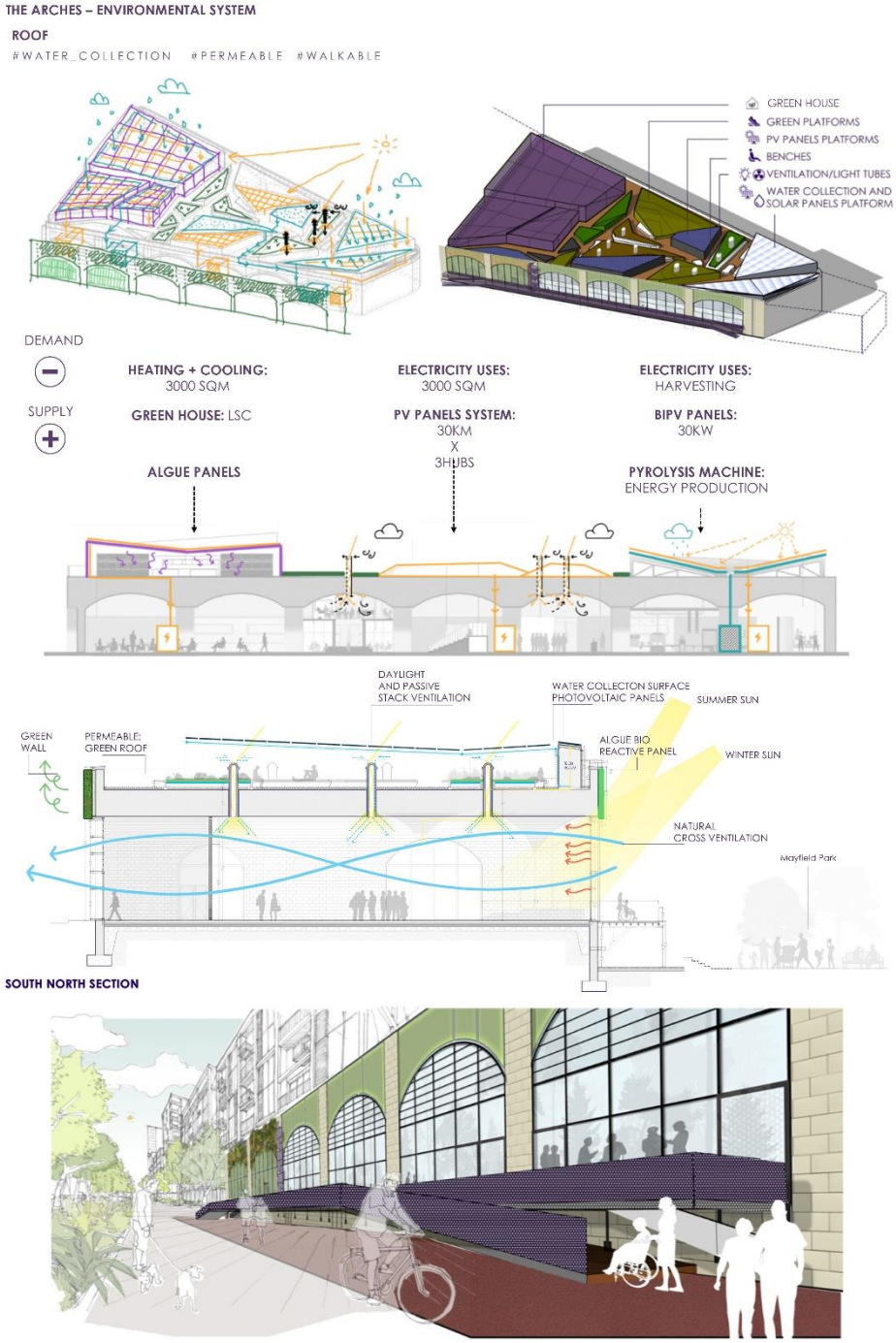

Figure 7. Mayfield Arches environmental technological design strategies and detailed solutions. Credits: P. Altamura, L. Pedata, M. El Masri, F. Giani, S. Hamza.

4.3 Mayfield adaptive reuse design scenarios

The proposed methodology is also at the core of the project proposals gathered under the research and experimentation activity developed at MSA by a team under Loris Rossi's guidance, in the framework of the FLUX ATELIER in 2023. The research aimed at speculating on the cultural, social and environmental assets offered by the abandoned infrastructures in Mayfield. Central to FLUX, the archipelago concept recognizes loosely connected fragments and ties them together. The FLUX Atelier responded to Mayfield's urban regeneration through the Archipelago[9] concept. The Archipelago idea shifts the approach of urbanism from large-scale urban master planning to working with the city as a series of islands forming an Archipelago. The proposition explored is that each one of these "islands can reconnect city fragments through an incremental sequence of green infrastructures and, collectively, as an Archipelago, can create an alternative mode of planning the city". [19] Manchester city centre offers a series of natural and built infrastructure linked with interrupted and isolated elements of the city: The railway viaducts, the new Mayfield Park, the public realm, the River Medlock and the Mancunian Way. The sites selected by the atelier include one of the following infrastructures: Motorway, Railway, Parklands and Public realm, The Medlock River. Along these infrastructures, many sites act like isolated, deserted islands. The urban regeneration projects were aimed at reconnecting Mayfield to the rest of the city, activating a *state of change*.

What if a building behaves like a wall? The project "THE INHABITED WALL: MAYFIELD LIBRARY" (Fig. 8) proposes a new structure parallel to the arches running along the Piccadilly line railway tracks north of the Mayfield site. The nearby viaduct is incorporated into the scheme and becomes a continuation of the main object, but the arches' spatial resources are used for secondary purposes. The new building runs parallel to the viaduct, and its slender volume seems to mimic the existing infrastructure. The building is distanced from the rail bridge and raised from the site to allow an open ground floor to respect the existing abandoned green spaces. On top of the viaduct, an unkempt 'urban forest' continues Mayfield's abandoned greenery. The project operates as a Necropolis – leaving nature above the viaduct and the new building beside it. The library and recreational functions are on the lower floors and underneath the arches. The space between the arches and the new library volume is inhabited by vertical connections and suspended walkways that are parasitic to the viaduct arches containing reading spaces. The environmental strategies adopted are ground source heat pumps and solar tracking PV panels. Recycled steel and prefabricated panels as construction materials.

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[9] The work developed by Atelier Flux 2022-23 has been characterized by an in-depth study and investigation of the book: *The City in the City – Berlin: A Green Archipelago*. A manifesto (1977) by Oswald Mathias Ungers, Rem Koolhaas, et al., A critical edition by Florian Hertweck and Sébastien Marot, Lars Müller Publishers.

Figure 8. “THE INHABITED WALL: MAYFIELD LIBRARY”. Credits: Loris Rossi, Ella Walklate and Louis Louth, 2022-23.

What if a building behaves like a natural ruin? The “WILD HABITAT RESOURCE” project (Fig. 9) introduces new punctual structures - a series of cone-shaped chambers/pods where spores are harvested. These structures are aimed at capturing the state of transition of the site, at preserving and multiplying the small pockets of life that exist in some of the most unlikely places. The project is preceded by a careful analysis of the biodiversity across city fragments, which provided the foundation for an interactive preservation model. Once the pods have reached the end of the occupancy phase (35 years), the plan is to transport them to areas throughout the city where they can continue to serve as a rewilding biome. The pods are distributed around and inside the existing arches, using them as voids that generate interstitial spaces for circulation and observation when interacting with the new volumes. The ground floor of the structures welcomes cafés and resting areas for the public and storage/selling facilities for the spores produced inside the pods on the first floor. As a first indicator of circularity, the leftover coffee grounds are used as fertilizer in the workshops on the first floor. The first floor is inaccessible directly from the ground floor and is reserved for educational workshops where spores/seeds are grown. Customers can gain access to the growing pods via a walkway.

Figure 9. “WILD HABITAT RESOURCE”. Credits: Loris Rossi, Ella Walklate and Joseph Marsden, 2022-23.

What if a building behaves like a void? Lastly, the project “INVERTING MAYFIELD. AN EXHIBITION OF DARKNESS AND LIGHT” highlights the symbiotic relationship of the river with the area’s economic and social health (Fig. 10). “A space celebrating space and light. But also darkness and voids. The inverted archipelago map of Mayfield revealed that the positive and negative are two interconnected entities. The void creates the space and, in other cases, the absence of it. Thus, the only constant that stays unchangeable are the boundaries which separate the one from the other”. In reality, the building behaves like arches. The building is carved by the existing nature and river, establishing a relationship with the river fragment and creating an “Inverse Archeology” just like the negative spaces under archers. This way, the existing nature of the river is preserved. “The void allows for sunlight and rainwater to pass through the building and connect the sky to the earth. Thus, creating a new ecosystem that thrives on its own and continues to grow”.

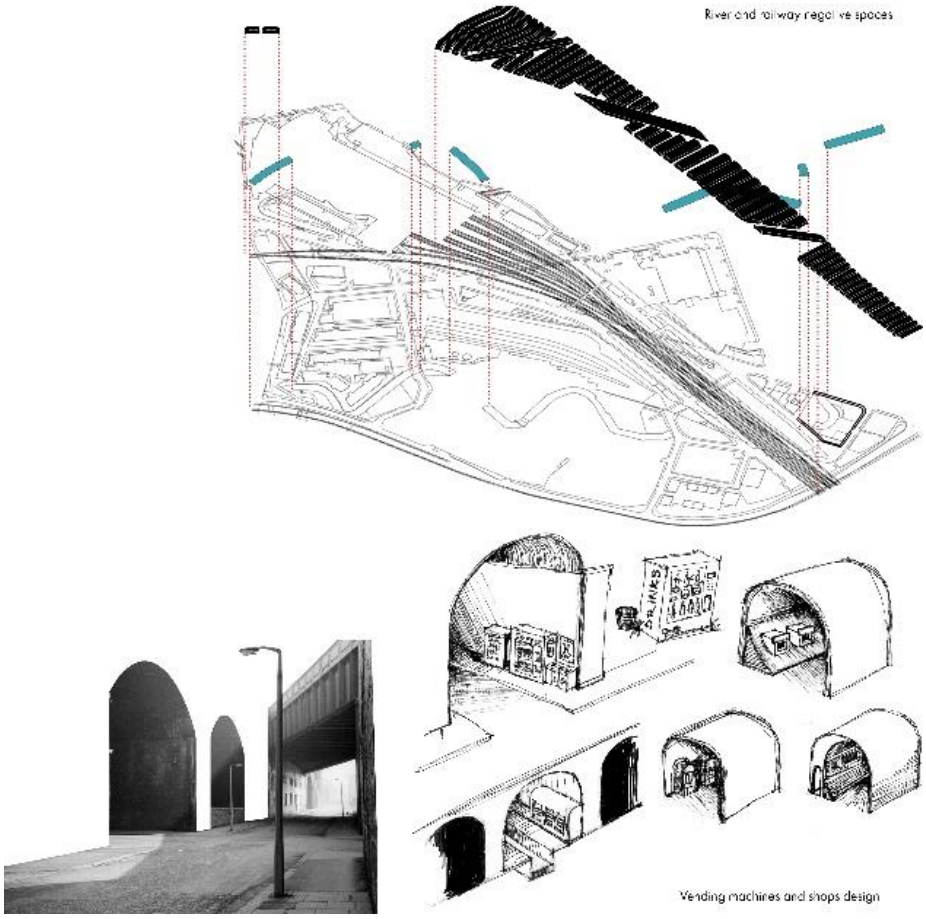

Figure 10. “INVERTING MAYFIELD. AN EXHIBITION OF DARKNESS AND LIGHT”. Credits: Loris Rossi, Ella Walklate and Silvia Nedyalkova, 2022-23.

5. Conclusions and research recommendations

This paper presented a methodology developed through the comparative analysis of international case studies that supports the evaluation and definition of adaptive reuse design scenarios for disused elevated railways centred around a sustainable, circular and dynamic regenerative process. The proposed methodology and the design scenarios acknowledge that “scale” and “time” are vital aspects of adaptive reuse projects, considering that “Both the physical infrastructure and the social value must be weighed up against the site’s programmatic aspects and the potential for future growth”. We need to engage with more extensive spatial and temporal parameters. “…considering the project in terms of different material, spatial, cultural, and economic resources the whole

site embodies. In doing so, it is possible to develop a rich and multifaceted approach to redevelopment, one which optimizes and augments the value present". [8 p. 183]

A "rich and multifaceted approach to redevelopment" is one that "optimizes and augments the value present" [8 p. 185]. Since we need to respond to the resources we are presented with and carefully observe and weigh what is there to reuse, we are certainly considering the existing potential of the site and structure, including the structure's identity and historical, social and cultural value. Hence, approaching existing resources in a new way automatically guarantees a more sustainable practice.

Unfortunately, different barriers still inhibit the widespread implementation of railway viaducts' adaptive reuse strategies. These include the regulations that should support the activation of these marginalized spaces and the multiple interests on such infrastructures from different stakeholders. Therefore, approaching existing resources in a new way implies strategies of care and negotiation as a methodology to develop designs.

In conclusion, reflecting on the research results, different research perspectives open up. First, to enable the quantitative evaluation of the environmental benefits derived from reusing these complex and large assets, the Research Group intends to implement the methodology for estimating the material stock of existing buildings developed by one of the authors in previous studies focusing on industrial heritage [20 pp. 1-18]. This methodology allows accounting for typologies and volumes of existing materials and their embodied carbon - an indicator chosen to correlate circular design strategies, including heritage adaptive reuse, to their climate mitigation potential. Finally, when studying the possibilities for increasing resilience through the adaptive reuse of these assets, the research will adopt microclimatic simulation and modelling dynamic tools to address goals such as heat island effect reduction in a more focused and effective way.

Authors contributions

L. Pedata: Resources, Formal analysis, Conceptualization, Supervision, Writing - original draft, Writing - review & editing. Introduction, State of the art, Results, and Conclusions.

P. Altamura: Resources, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. State of the art, Methodology, Results, and Conclusions.

L. Rossi: Resources, Conceptualization, Writing - original draft. Introduction, Results, and Conclusions.

Acknowledgement

This contribution reports the results of parallel, interconnected research and design experimentation activities developed by the authors with the following collaborations.

The research and design experimentation described in Par. 4.2 was developed by P. Altamura and L. Pedata in collaboration with Mahassen El Masri, Flaminia Giani and Sarah Hamza, at "Sapienza" University of Rome, Planning Design Technology Department.

The research activity reported in Par. 4.3 was developed by Dr Loris Rossi with Ella Walklate in collaboration with Louis Louth, Joseph Marsden, and Silvia Nedyalkova. The research was also possible thanks to the collaboration with Atelier FLUX: Dan Dubowitz, Dr Loris Rossi, Dr José Hidalgo, Dr Ray Lucas, Christopher Maloney, and John Wood from the Manchester Metropolitan University - Manchester School of Architecture, 2023 BA (Hons). Source: MSA website

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