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ARTICLE

Urban Resilience through Design: A Holistic Framework for Sustainable Redevelopment of Brownfield Sites

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ABSTRACT

This study presents a holistic framework for sustainable urban design, using the proposed redevelopment design of Berlin's Tegel Airport as a case study. The research addresses the need for comprehensive, real-world applications of sustainable urban design principles in the context of climate change and urban challenges. The proposed framework integrates multiple sustainability elements, including adaptive reuse, innovative energy systems, and a 'resource community' concept. Key features include mixed-use development, a phased approach, and innovative mobility solutions. The study demonstrates the practical application of urban resilience theory, adaptive reuse concepts, circular economy principles, and compact city theory. Findings reveal the potential for significant environmental benefits, including reduced energy consumption and improved resource efficiency. The framework shows promise in fostering social cohesion through mixed-use spaces and community-centered design. Economic implications include creating local job opportunities and the potential for long-term cost savings through efficient resource management. However, challenges such as initial implementation costs and the need for stakeholder coordination are identified. The study contributes to sustainable urban planning by bridging the theoretical concepts and practical implementation gap. It offers a model for transforming urban brownfields into sustainable communities, providing valuable insights for urban planners, policymakers, and developers. Future research directions include longitudinal studies of implemented projects and comparative analyses across diverse urban contexts.

Keywords: Sustainable Urban Design; Adaptive Reuse; Resource Community; Brownfield Redevelopment; Urban Resilience Framework

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1. Introduction: The Research Need for a Holistic Approach to Sustainable Urban Design

1.1. Background and Aim of the Research

Extreme weather caused by the climate crisis is increasingly severely impacting cities. Consequently, there is a pressing need to develop urban design strategies prioritizing environmental stewardship, community-centric planning, and adaptability to disruptions. One such approach is the concept of "urban resilience," which focuses on designing cities that can "survive, adapt, and grow" in the face of various stresses and shocks [1, 2]. This leads to a need for an integrated approach to sustainable urban design. A holistic understanding of the complex interrelationships between the various urban systems, including infrastructure, transportation, energy, and ecology, is crucial for developing long-term, climate-adaptive solutions [3].

The Tegel Airport site in Berlin, Germany, presents a unique case study for implementing holistic, sustainable urban design strategies. Established in 1906 and serving as West Berlin's primary airport since 1960, the site's closure in 2021 as part of Berlin's airport consolidation plan has created a 460-hectare canvas for redevelopment. With its rich historical significance and strategic location near major universities and companies, this brownfield site offers an exceptional opportunity to bridge the gap between theoretical sustainable urban design concepts and their practical application. Its proximity to Berlin's city center and existing transportation infrastructure provides an ideal setting for implementing sustainable urban redevelopment concepts. The site's industrial legacy and environmental challenges make it a prime example for demonstrating innovative remediation techniques and green infrastructure solutions. Furthermore, the political and economic context surrounding Tegel's closure and redevelopment plans offers valuable insights into the complexities of large-scale urban renewal projects, including stakeholder engagement, policy considerations, and the balance between preserving historical elements and fostering future-oriented development. This comprehensive redevelopment opportunity aligns with the study's aim of presenting a holistic approach to sustainable urban transformation in the context of climate change and contemporary urban challenges.

In this context, this article's suggestion that the Tegel Airport site be transformed motivates a unique opportunity to implement a comprehensive, resilient urban design strategy. After closing its operations in 2021, the Tegel Airport site's redevelopment offers a rare chance to rethink the traditional top-down approach to urban planning and adopt a more holistic, systems-based perspective [4]. This would involve carefully considering the site's environmental, socio-cultural, and economic impacts and connections to the broader urban fabric [5].

1.2. The Need for Research on Sustainable Urban Design in Real-World Urban Spaces

Previous research on urban sustainability has covered various topics, including environmental sustainability, social equity, economic development, and urban resilience. Many studies have focused on developing assessment methods and indicators to measure urban sustainability progress [6–12]. The spatial distribution of urban resilience and its influencing factors was analyzed in 56 Chinese cities [12], improving our understanding of urban sustainability. Further exploration of the connections between cities, technology, and ecology [13] suggested urban strategies for a sustainable society. This study emphasized the importance of integrating technological innovations with ecological considerations in urban planning, highlighting the potential for sustainable solutions to address environmental challenges. Key emerging themes include smart cities, urban metabolism, and the integration of sustainability goals into urban planning and policy [13, 14]. However, much of this research has been theoretical or conceptual, with limited practical application to specific urban areas [15, 16]. The field has evolved from primarily environmental concerns to a more holistic view incorporating urban sustainability's social, economic, and governance aspects. However, there remains a gap in comprehensive, real-world implementations [17].

Studies with specific urban design approaches for sustainability have proposed various strategies and interventions. Some key focus areas include green infrastructure, compact urban forms, and transit-oriented development [18]. Furthermore, the exploration of land transfer policies highlighted how they can promote a new type of urbanization in China [19], underscoring the significance of effective land use strategies for sustainable urban development.

Researchers have examined how urban design can promote energy efficiency, sustainable transportation, and climate change adaptation. There is growing interest in nature-based solutions and biophilic design to enhance urban ecosystems [20–23]. In rural-urban transition zones, the factors influencing changes in rural residential areas were examined [24] offering insights for sustainable development in these regions. However, many of these studies have focused on individual components or isolated aspects of urban design rather than presenting a holistic approach that integrates multiple sustainability elements in a real urban context [25, 26].

The research gap lies in the lack of comprehensive studies implementing a full range of sustainable urban design components in a specific, actual urban area as a holistic approach. While existing research has provided valuable insights into various aspects of urban sustainability and design strategies, there is a need for more integrated, practical applications that demonstrate how multiple sustainable design elements can work together in a real-world urban setting [27, 28]. Ventilation analysis of urban functional zoning in Guangzhou demonstrates that considering specific urban contexts in sustainability research is crucial [9]. This gap highlights the importance of developing and studying comprehensive, implementable approaches to sustainable urban design that simultaneously address environmental, social, and economic dimensions in specific urban contexts.

2. Methodology

2.1. Conceptual Framework: Merging Established Theories for Innovative Urban Design

The theoretical foundation of this holistic framework for sustainable urban design draws from several interconnected concepts in urban planning and sustainability. As cities face increasing challenges from climate change, resource depletion, and rapid urbanization, there is a growing need for integrated approaches to address these complex issues. This framework synthesizes five vital theoretical perspectives: urban resilience theory, adaptive reuse concept, circular economy principles, compact city theory, and the integration of these theories. Together, these concepts provide a robust academic foundation for reimagining urban spaces, particularly in the context of brownfield redevelopment projects like the Tegel Airport site in Berlin.

Urban resilience theory forms a cornerstone of this framework, emphasizing the creation of adaptable urban systems capable of withstanding and recovering from various stresses and shocks. Urban resilience is defined as "the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance" (p. 39) [1]. This concept aligns with the phased development approach and flexible design strategies proposed for the Tegel Airport site. The importance of integrating resilience thinking into urban planning and design is further emphasized, particularly in the context of climate change adaptation [29]. A notable application of urban resilience principles can be seen in Rotterdam's climate adaptation strategy. In an analysis of Rotterdam's approach, innovative water management systems and multifunctional urban spaces enhanced the city's ability to cope with climate-related challenges [30]. This case demonstrates how resilience thinking can be integrated into urban planning to address specific environmental vulnerabilities.

Central to this framework, the adaptive reuse concept involves repurposing existing infrastructure while preserving cultural heritage and reducing resource consumption. The environmental and economic benefits of adaptive reuse in urban regeneration projects [31], which is evident in the plans for repurposing the Tegel Airport's terminal building and runways. The social sustainability aspects of adaptive reuse is further emphasized, noting its potential to maintain community identity and social fabric [32]. An exemplary case of adaptive reuse is the High Line in New York City. Through the examination how this abandoned elevated railway was transformed into a public park, the potential of adaptive reuse to create vibrant urban spaces while preserving industrial heritage is demonstrated [33]. This project showcases how adaptive reuse can contribute to urban regeneration and enhance public spaces.

Circular economy principles are integral to the 'resource community' concept proposed in this framework. The circular economy is defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" (p. 759) [34]. This is reflected in the Tegel site's proposed energy systems and waste management strategies. An exploration of the application of circular economy principles in urban planning [35], highlight the potential to create more sustainable and resilient cities. Amsterdam's circular city initiative provides a compelling case study. Amsterdam's approach to implementing circular economy principles at the urban scale include strategies for waste reduction, resource recovery, and sustainable construction [36]. This case illustrates how circular economy concepts can be integrated into urban policy and planning to promote sustainability.

The 'city of short distances' concept in this framework aligns closely with compact city theory. As critically examined, the potential benefits of the compact city model, in reducing energy consumption and promoting social interaction is highlighted [37]. While acknowledging potential challenges, the framework incorporates vital aspects of compact city design, such as mixed-use development and sustainable mobility options. The dimensions of the compact city was further explored, emphasizing the importance of context-specific applications [38]. The framework's approach to density and land use mix reflects these principles, aiming to create an efficient and livable urban environment. Singapore has long been recognized for implementing compact city principles, balancing high-density development with green spaces and efficient public transportation [39].

Integrating these theories provides a robust academic foundation for the proposed framework. A transdisciplinary approach to urban planning and design is advocated, emphasizing the need to integrate diverse theoretical perspectives to address complex urban challenges [40]. And the importance of integrative approaches in urban sustainability transformations is further emphasized, highlighting the need for holistic strategies that address multiple dimensions of urban systems [41]. The redevelopment of the Bahnstadt district in Heidelberg, Germany, offers an example of how these theories can be integrated into practice, combining elements of urban resilience, adaptive reuse, circular economy, and compact city design [42]. The Bahnstadt development demonstrates how a holistic approach to urban planning can create sustainable, resilient, and livable urban environments. By synthesizing these theoretical perspectives and drawing lessons from diverse case studies, the framework offers a nuanced and comprehensive approach to brownfield redevelopment, grounded in established urban planning and sustainability principles, while offering innovative applications.

2.2. Methodological Framework for Sustainable Urban Redevelopment: A Case Study of Berlin's Tegel Airport

The methodology for this research on the sustainable redevelopment of Berlin's Tegel Airport is structured around a comprehensive case study approach, focusing on the site as a representative example of large-scale brownfield redevelopment. This study employs a mixed-methods design combining qualitative and quantitative data to provide a well-rounded analysis of the redevelopment process.

Data collection involves several key components. First, a thorough document analysis is conducted, reviewing existing plans, policies, and reports on the Tegel Airport redevelopment. This is complemented by a detailed site analysis assessing the area's physical characteristics, existing infrastructure, and environmental conditions. Additionally, semi-structured interviews with urban planners, policymakers, developers, and community representatives involved in the project are conducted to gather insights and perspectives from various stakeholders. A comparative analysis of similar brownfield redevelopment projects in other cities is also performed to identify best practices and potential challenges. The analytical framework uses indicators based on the theoretical principles of urban resilience, adaptive reuse, circular economy, and compact city design. These indicators help to assess the sustainability and resilience of the proposed redevelopment plans. Geographic Information Systems (GIS) mapping and spatial analysis are utilized to evaluate land use patterns, connectivity, and potential environmental impacts. Scenario planning is also employed to explore different development options and their long-term implications.

Following the analytical phase, a conceptual master plan for the Tegel Airport site integrates sustainable urban design principles. Detailed design proposals for key areas within the site illustrate how these theoretical concepts can be applied in practice. Finally, findings from all stages of the research are synthesized to develop a comprehensive framework for sustainable brownfield redevelopment. This synthesis culminates in policy recommendations and design guidelines that can be applied to similar projects in other urban contexts, ensuring that the resulting framework is both academically rigorous and practically applicable.

3. Embodying Sustainable Design Principles as Planning Concept

3.1. Sustainable Urban Design Principles

Sustainable urban design encompasses a multifaceted approach to city planning that necessitates a comprehensive awareness of potential risks and disruptions, including those stemming from climate change, economic volatility, and security concerns [43, 44]. The principles underpinning sustainable urban design are instrumental in shaping the trajectory of contemporary urban environments, where the seamless integration of environmental, economic, and social factors is paramount. This holistic approach to urban development seeks to create resilient, adaptable, and livable spaces that withstand and thrive amidst various challenges.

When contemplating sustainable building culture, it is essential to consider not only technical measures related to energy efficiency, such as the implementation of solar cells and the utilization of high-performance insulating materials, but also to address aspects on a broader scale of ecological, economic, and socio-cultural factors. These three interconnected domains offer a number of opportunities for implementing appropriate sustainability measures in urban planning, as illustrated in **Figure 1**. It is crucial to note that each intervention, ranging from macro-level urban planning strategies to specific construction measures, often simultaneously addresses multiple aspects of sustainability. For instance, an urban agriculture initiative enhances ecological quality and provides economic advantages while fostering socio-cultural benefits by creating a communal space for residents and local producers to interact. This synergistic approach to sustainability can be observed at various scales, with each level incorporating specific elements tailored to promote sustainable development.

From the perspective of energy-efficient planning, the development of sustainable and energy-efficient urban structures necessitates a sophisticated strategy that accounts for complex interrelationships and allows for flexible adaptation to future developments. This approach requires meticulous coordination of various components within the overall urban framework. Efficient land use and optimized technical infrastructure serve as the foundation for energy-efficient settlement structures. Consequently, sustainable planning commences with the judicious distribution of land use and the spatial coordination of demand and potential, as reflected in land use plans, informal transportation schemes, urban development concepts, and energy use plans. **Figure 2** comprehensively summarizes the critical aspects of energy-efficient planning, highlighting the intricate relationships between different urban systems and their collective impact on sustainability.

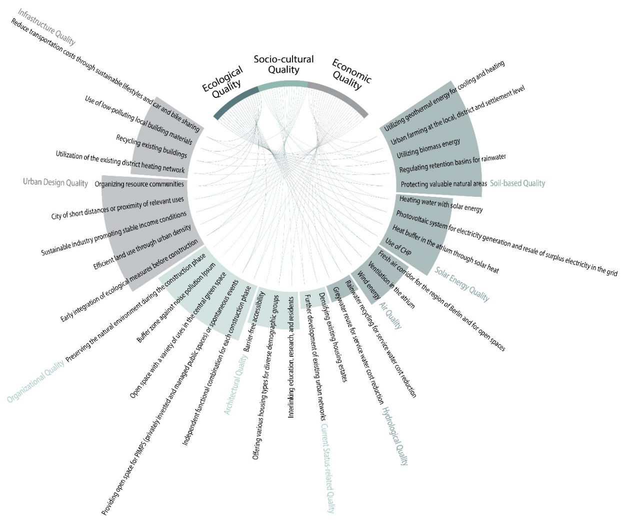


Figure 1. Aspects of sustainable urban design and implementation components.

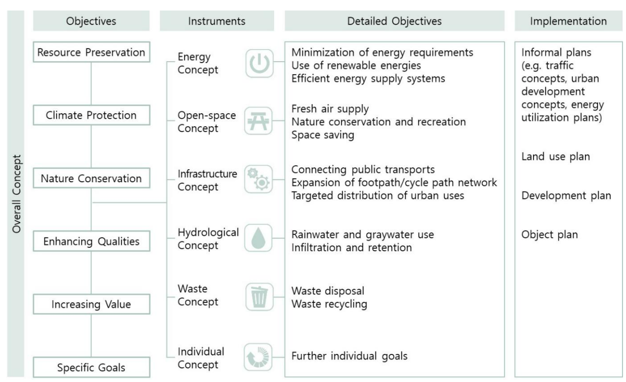


Figure 2. Development of the overall concept.

Several key strategies can be employed to harmonize various urban components for energy efficiency planning in the Tegel Airport redevelopment project. First, integrating land use planning with energy systems is essential. The "city of short distances" concept reduces transportation needs and facilitates efficient energy distribution through co-located residential, commercial, and recreational spaces, supporting district heating and cooling systems [45]. Adaptive reuse of existing infrastructure, such as the airport terminal, allows for retrofitting with modern energy-efficient technologies, preserving embodied energy while enhancing performance [31]. Additionally, the "resource community" model integrates energy production, waste management, and urban agriculture, further optimized by smart grid technologies for real-time energy flow management [46]. Water management also plays a critical role; integrating urban wetlands and retention areas supports biodiversity and contributes to natural cooling and water treatment processes. This aligns with nature-based solutions that enhance both environmental and energy goals [28]. Finally, a phased development strategy provides flexibility for incorporating emerging technologies over time while allowing for continuous monitoring and improvement of energy systems [40]. By employing these strategies, the project can create a highly efficient and sustainable urban environment tailored to its specific context.

3.2. Development Opportunities and Concept Transferred to the Study Site

The case study area, situated at a considerable distance from Berlin's city center, benefits from its historical role as a former air traffic hub endowed with excellent public transportation accessibility. This strategic location is further enhanced by the existing city center, Kurt-Schumacher Platz, within the target area, including a stop on the tramway network. This connectivity provides a robust foundation for future urban development initiatives. Additionally, the low-density residential zones in the surrounding hinterland also present a promising starting point for revitalizing the area. By leveraging these existing transportation and residential infrastructures, urban planners can facilitate a seamless transition toward a more vibrant and sustainable urban environment.

Conversely, the area's natural elements currently lack distinctive features that could otherwise contribute to its identity. However, this perceived weakness can be transformed into an opportunity to enhance the quality of life in Berlin's northeastern sector. Developing this area as a pilot zone for renewable energy deployment can serve as a model for sustainable urban development. Furthermore, addressing the general public's underutilization of open spaces for leisure activities presents an additional strategy for enhancing community engagement and environmental quality within the study area.

The overarching objective is to transform Tegel into Berlin's future as a "sustainable city," featuring an international center dedicated to innovative environmental technologies. This center aims to be unparalleled globally, showcasing Germany's leadership in research and production within this field. The comprehensive planning concept applied to the study site is depicted in **Figure 3**. This concept envisions the study site as an economic hub for the region, utilizing the orientation of the existing runway to create an experimental field that serves as a living test site for future eco-technologies. This field is interconnected by a green axis that includes a potential fresh air corridor, promoting ecological sustainability and urban livability.

Moreover, the existing residential complexes, aside from the study site's northern and southern sections, have been preserved and strategically densified. This densification serves as an initial step toward revitalizing the entire area, fostering increased residential capacity while maintaining community integrity. Through these concerted efforts, Tegel can emerge as a pioneering example of sustainable urban transformation, integrating cutting-edge environmental technologies with thoughtful urban planning to create a resilient and forward-looking urban landscape.

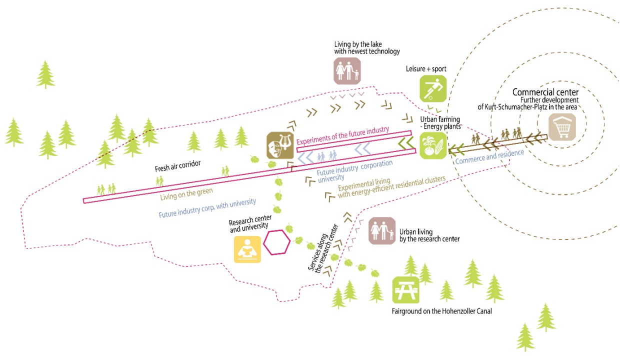


Figure 3. Overall planning concept of the study site.

4. Integrating Sustainability into Urban Planning Framework

The urban planning framework was concretized based on the overall planning concept, as shown in **Figure 4**. At this stage, sustainable urban planning strategies were applied through 1) biodiversity preservation through open space structure, 2) a proposal for the construction phase to maintain the site's vitality, and 3) "Resource Community" as a resource-efficient and socio-ecologic application. Regarding resource community, sub-themes such as 3.1) renewable energy integration through supply infrastructure and 3.2) hydrological and waste management are discussed, stretching to integration at the neighborhood level in the next section.

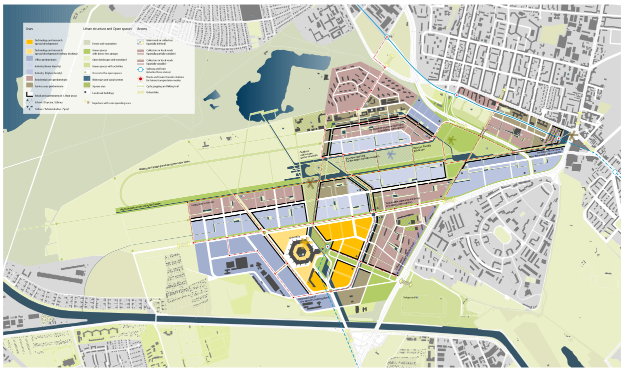


Figure 4. Urban planning framework of the study site.

4.1. Biodiversity Preservation through Open Space Structure

The ecological design of the study area prioritizes the preservation and enhancement of biodiversity through a carefully planned open space structure. A critical component of this design is the fresh air corridor, which extends from Tegeler Forst and Jungfrauheide via the fairground to Berlin's city center. This corridor serves a dual purpose: it maintains its original function of supporting urban climate control and biodiversity while simultaneously becoming a nexus for urban activity through events and concerts. The open space structure is meticulously planned through the cross-connection of an island-like square featuring an open-air stage, effectively connecting the city's northern and southern parts. This design facilitates air circulation and creates a multifunctional space encouraging social interaction and community engagement. The main flow of visitors is strategically directed along the former runways, repurposing these historical elements while preserving their linear character.

The urban fabric transitions from a vibrant, service-oriented atmosphere at Kurt-Schumacher-Platz in the east to more leisure-focused facilities and urban agriculture near the retention water area. This gradual shift in land use creates a diverse and dynamic urban environment that caters to various needs and activities. The inclusion of a mobility experimentation field represents an innovative approach to urban design, where research institutes can test and showcase the latest mobility innovations. This not only contributes to technological advancement but also engages the local community by making these innovations "visible" and potentially accessible to residents and passers-by. The open space continuum is further enhanced by a central square at the former terminal building, which is repurposed to house university and research facilities. This adaptive reuse of existing infrastructure demonstrates a commitment to sustainable development practices. The open space atmosphere is maintained through a carefully designed sequence of zones, including a service area and a fairground, before transitioning back to green spaces. This thoughtful arrangement ensures a harmonious blend of built and natural environments, promoting both ecological sustainability and urban vitality.

The design of open spaces in the study area goes beyond mere aesthetic considerations, actively promoting biodiversity and ecosystem services while enhancing urban life quality. Drawing inspiration from the concept of "nature-based solutions," the open space structure incorporates a variety of habitats that support local flora and fauna [28]. For instance, creating urban wetlands along the water retention areas manages stormwater and provides crucial habitats for amphibians and water birds. Native plant species are prioritized in landscaping to support local pollinators and create resilient green corridors. These biodiverse spaces are seamlessly integrated with urban functions, creating opportunities for environmental education and citizen science initiatives. Interactive information panels and guided nature walks can foster a deeper connection between residents and their local ecosystems. Moreover, the design incorporates "productive landscapes" such as community gardens and food forests, enhancing biodiversity and promoting food security and social cohesion [47]. The mobility experimentation field is bordered by "living labs" where researchers can study urban ecology in real time, providing valuable data for adaptive management strategies. By interweaving biodiversity-rich spaces with areas of high urban activity, the design creates a unique "biophilic urbanism" that enhances both ecological and social resilience [48]. This approach contributes to the city's green infrastructure network. It creates a distinctive sense of place, where the boundaries between nature and urban life are blurred, fostering a new kind of urbanity deeply connected to local ecosystems.

This integrated approach to ecological design and open space structure demonstrates a holistic vision for urban development that balances environmental preservation, social engagement, and technological innovation. By carefully orchestrating the interplay between natural systems and urban functions, the study area sets a precedent for sustainable urban planning that can enhance both biodiversity and quality of life in cities.

4.2. Proposal for the Construction Phase Maintaining the Urban Vitality

The proposed construction phase strategy is designed to maintain urban vitality throughout the development process while ensuring the stability of existing settlements, as illustrated in the upper part of **Figure 5**. This phased approach prioritizes the initial maintenance and enhancement of landscape areas, recognizing the importance of green spaces in establishing a sustainable urban environment from the outset. Each development section is planned to combine housing with workspaces, local amenities, and leisure facilities. This mixed-use approach is fundamental to creating a vibrant, self-sustaining community that reduces the need for long-distance travel and promotes a high quality of life for residents. The gradual implementation of this development strategy allows for stable growth, enabling the community to evolve organically while minimizing disruptions.

An exemplary process detailing the transition from construction phases 1 to 2 has been developed in **Figure 5**. It illustrates the projected evolution of investment requirements, resident population, and visitor numbers. This data-driven approach provides stakeholders with a clear understanding of the development's trajectory and potential economic impacts. To maintain activity and engagement during transition periods between construction phases, the plan incorporates various interim uses. These temporary activations include spaces for extreme sports (X-sports), urban agriculture initiatives, and Private Invested and Managed Public Spaces (PIMPS). These interim uses serve multiple purposes: they prevent the emergence of unused or derelict spaces, provide immediate value to the community, and allow for experimentation with different land uses that could inform future permanent developments. This flexible and adaptive approach to urban development ensures that the area remains dynamic and responsive to community needs throughout the construction process.

The phased construction strategy maintains urban vitality and has significant socioeconomic implications. Job creation is a key benefit, with each phase generating employment opportunities in construction and services. Private sector-led urban development projects can contribute significantly to local economic growth[49]. However, this growth may lead to gentrification risks. To mitigate these, the proposal includes inclusionary zoning policies, ensuring that 20–30% of new housing units are affordable[50]. The mixed-use approach and emphasis on local amenities aim to preserve neighborhood character and support existing businesses. Interim uses like urban agriculture foster local entrepreneurship and community engagement. By balancing job creation with affordability measures, the phased approach seeks sustainable growth while minimizing displacement.

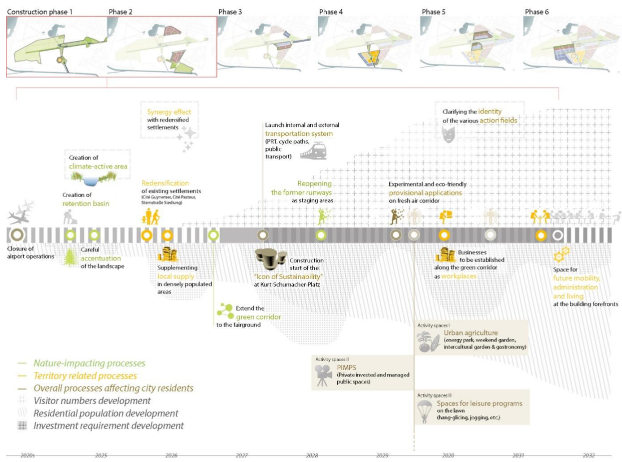


Figure 5. Proposed construction phase to maintain the urban vitality (above) with the detailed process from phases 1 to 2 (bottom).

The phased construction strategy and interim use approach highlight how temporary interventions can catalyze long-term change, addressing concerns raised regarding gentrification through mixed-use development and inclusionary zoning policies[50]. Additionally, our focus on maintaining green spaces throughout the redevelopment process supports findings on the importance of urban green spaces for community well-being[51]. This integrated approach offers a valuable framework for sustaining urban vitality during large-scale projects.

4.3. Resource Community: A Resource-efficient, Socio-Ecologic Application

4.3.1. Renewable Energy Integration through Supply Infrastructure

The integration of renewable energy sources and the optimization of supply infrastructure are crucial components of the sustainable urban design strategy for the Tegel site. The energy supply and disposal system are partially provided by Tegel Airport's existing heating plant, which is being repurposed and upgraded to meet the new development's needs. This approach exemplifies the principle of adaptive reuse in sustainable urban development.

A key feature of the energy strategy is the implementation of combined heat and power plants (CHP) for each "resource community." This decentralized approach to energy production, which increases supply efficiency, is proposed as one of the sustainable urban design components aimed at reducing the load on the city's central energy infrastructure. Distributing energy production across multiple smaller units makes the system more resilient and efficient, potentially reducing transmission losses and increasing overall energy efficiency. The heating supply within the area leverages and expands upon the existing district heating network. This extension ensures that the entire TXL site is covered by the district heating system, providing a reliable and potentially more sustainable heat source for the development. The integration of district heating aligns with best practices in sustainable urban energy systems, as it allows for more efficient heat distribution and the potential use of renewable or waste heat sources. In addition to energy considerations, the plan incorporates hydrological elements that serve multiple functions. A retention basin with green strips along the water's edge is designed to allow for slower precipitation seepage. This feature not only aids in stormwater management but also incorporates graywater purification functions. Such integrated water management strategies are essential for creating resilient urban environments that can adapt to changing climate conditions and support local ecosystems.

Providing quantitative support for the proposed sustainable urban design strategies, we can draw on recent comparable studies and industry standards. For instance, research on fourth-generation district heating systems indicates potential primary energy savings of 30–40% compared to conventional systems [52]. Applying this to an estimated 500-hectare development area could project annual energy savings of 150–200 GWh. Regarding CHP plants, a study shows that decentralized CHP systems can achieve overall efficiencies of up to 85% [53]. For a development of this scale, implementing CHP could result in primary energy savings of approximately 35–45%, potentially reducing CO_2 emissions by 60,000–80,000 tons annually, based on average urban energy consumption patterns. The retention basin's impact on water management can be quantified using recent urban hydrology models. Assuming a 10-hectare retention area, we could expect it to manage approximately 60,000–120,000 m³ of stormwater annually, potentially saving €600,000–1,200,000 in water treatment costs yearly (based on recent urban water management cost data). These estimates provide a quantitative framework supporting the viability of the proposed sustainable urban design strategies, demonstrating the potential for significant energy savings, environmental benefits, and long-term cost-effectiveness.

The "resource community" concept presented in this study offers an innovative approach to sustainable urban design by integrating renewable energy, efficient infrastructure, and community-scale resource management. This model builds upon and extends existing research on urban metabolism [54] and circular economy in urban contexts [35]. Our approach uniquely combines decentralized energy production using CHP plants with integrated water management and adaptive reuse strategies, presenting a holistic vision of sustainable urban infrastructure. While the quantitative estimates provided are promising, it is essential to note that this concept requires empirical validation through implementation and longitudinal studies.

4.3.2. Hydrological and Waste Management Supporting Social Cohesion

As a part of the resource community, the quarter's resource cycle concept is centered on an innovative and holistic approach to hydrological and waste management, as **Figure 6** illustrates. This system begins with the water cycle and integrates various sustainable technologies and practices to create a closed-loop system that maximizes resource efficiency and minimizes environmental impact. This system's core is the production of biochar from black water using a pyregano plant. This process is complemented by the Terra Preta plant, which utilizes biomass from organic waste to produce organic fertilizer. Integrating these technologies demonstrates a sophisticated approach to waste management that transforms potential pollutants into valuable resources. The resulting organic fertilizer is directly applied in local urban agriculture initiatives, linking waste management and food production. This local food production system not only provides fresh produce to residents and professionals in the area but also contributes to creating a new, sustainable business model based on local products. The harvested products are sold in local supermarkets and utilized in bars and restaurants, further reinforcing the local economy and reducing the carbon footprint associated with food transportation.

Gray water management is addressed through a biological purification process that combines treated gray water with rainwater before discharging it into the retention waterfront area. This integrated water management approach addresses water quality issues and creates an attractive landscape feature. The multifunctional design of this water feature allows for seasonal adaptations, such as its use as an ice rink during winter seasons, thereby enhancing its value to the community year-round. Incorporating biophilic design strategies and green infrastructure planning principles ensures that the resource cycle contributes to urban biodiversity preservation. Moreover, this approach facilitates the creation of inclusive public spaces with specific ecological functions, demonstrating how sustainable resource management can be seamlessly integrated into the urban fabric to create ecologically sound and socially beneficial environments.

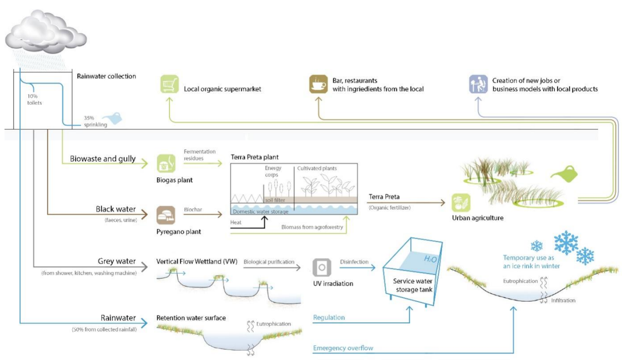


Figure 6. Resource cycle through hydrological and waste management (Seo[13], reconstructed by the author).

The resource community concept integrates adaptable energy supply and waste management systems to accommodate future development. The modular design of the combined heat and power plants (CHP) allows for scalability, ensuring energy production can meet growing demand. Similarly, the biochar and Terra Preta plants can expand as waste production increases. This flexibility enables the integration of emerging technologies, such as advanced anaerobic digestion, without disrupting existing infrastructure. The water management system, including retention basins and grey water purification, can also be upgraded to handle increased volumes or stricter standards. Urban agriculture initiatives can incorporate vertical farming or greenhouse systems to boost food production. By designing these systems with built-in adaptability, the resource community model promotes long-term sustainability and resilience in response to evolving urban needs.

This model enhances resource management and promotes community engagement and social cohesion. The model fosters social interaction and a shared understanding of responsibility by involving residents in local food production through urban agriculture initiatives. Community gardens and farmers' markets become central hubs for neighborhood gatherings, strengthening collective identity. Visible infrastructure, such as biochar production and water purification systems, is an educational tool that encourages residents to engage in sustainable practices. Additionally, multifunctional public spaces, like the adaptable retention waterfront area, provide venues for community events and recreational activities, further enhancing social bonds. By linking individual actions to community benefits, the "resource community" model cultivates a sense of belonging among residents, significantly contributing to social sustainability. This approach aligns with recent research emphasizing the role of socio-ecological innovation in urban sustainability transitions[55].

The integrated hydrological and waste management approach aligns with recent research on circular urban metabolism and nature-based solutions. This model builds on urban symbiosis concepts[56], emphasizing resource loop closure within urban systems. It addresses multiple sustainability dimensions by linking waste management to local food production and community engagement. Incorporating biophilic design reflects findings on the multifunctionality of nature-based solutions[57]. Overall, this resource community model provides a comprehensive framework for fostering resilient, socially cohesive urban environments.

5. Implementing Sustainability through Urban Design Components

Delving more detail into urban design components, a part of the study site, including urban uses such as industry, office, residence, public facilities (school, kindergarten, etc.), and public open spaces with waterfront, is visualized in **Figure 7**. Among sustainable urban design components,

1) "resource community" as a circular economy approach, 2) the concept of a city of short distances as a transit-oriented mobility concept, 3) adaptive building reuse, and 4) synergy effects through parking and shading concept are implemented to optimize resource efficiency.

Figure 7. Development plan for selected part of the case study site.

5.1. "Resource Community" as Circular Economy Approach

At the neighborhood scale, a "resource community" is proposed as an innovative approach to implementing circular economy principles. This model, which considers the individual operating times of various uses when planning pipeline networks, opens up new possibilities for collaboration and innovation. For instance, within a resource community managed by a single energy center, complementary uses such as residential and school, or residential and commercial, can be coordinated to optimize energy consumption throughout the day (**Figure 8**).

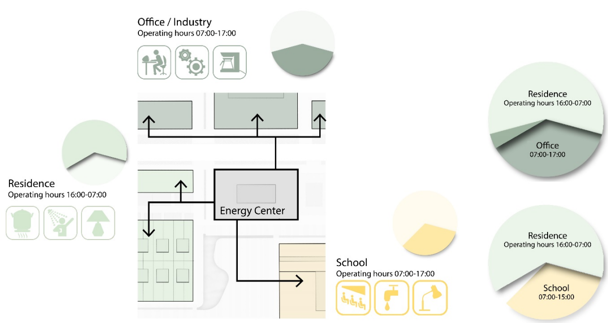


Figure 8. Synergy effect through diverse operative hours (Seo [13], reconstructed by the author).

The proximity of diverse building typologies and use types offers further synergistic effects due to their different supply requirements. By considering technical infrastructures and flexible network structures at an early planning stage, specific requirements can be coordinated to achieve desirable synergies in terms of energy efficiency. The integration of housing, leisure, commerce, and production within short distances creates opportunities for a coordinated supply system. This "resource community" approach allows for innovative energy management strategies, such as utilizing waste heat from industry and production to supply heat to residential and administrative buildings, but also significantly reduces energy costs and environmental impact. This principle can be extended to power supply through Combined Heat and Power (CHP) units and water supply systems, maximizing resource efficiency.

The ecological benefits of resource communities extend beyond energy management. These communities can collectively implement and benefit from sustainable technologies and practices such as solar thermal and photovoltaic systems, rainwater collection, plant purification systems, service water storage, Terra Preta systems, and urban agriculture initiatives. This collective approach enhances the efficiency of these systems and fosters a community-wide commitment to sustainability. Integrating these various elements – sustainable mobility, adaptive reuse, innovative parking solutions, and resource community concepts – the urban design strategy creates a holistic approach to sustainable urban development. This comprehensive strategy addresses environmental, social, and economic aspects of sustainability, positioning the development as a beacon of hope for future urban regeneration projects.

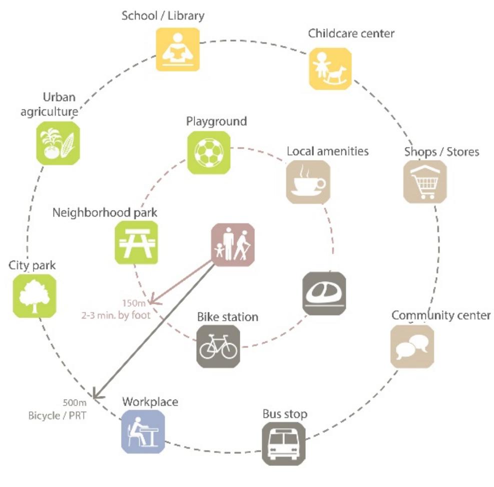
To address the practical aspects of implementing the "resource community" concept, several key considerations must be taken into account. Financial barriers present a significant challenge, as the implementation requires substantial upfront investment in infrastructure and technology. However, innovative financing mechanisms such as public-private partnerships, green bonds, and performance contracting models can help mitigate these initial costs [58]. Logistical challenges arise from coordinating diverse energy needs and supply systems within the community. Advanced energy management systems and innovative grid technologies are crucial for optimizing real-time energy distribution across different building types and uses. Lessons can be drawn from smart city initiatives like Amsterdam's Smart City program to address these complexities [59]. The regulatory framework poses potential obstacles, particularly regarding energy distribution and pricing. Engagement with local and national regulatory bodies is essential to develop supportive policy frameworks, allowing direct supply of solar electricity to tenants. Stakeholder engagement is another critical factor, as the success of the resource community hinges on buy-in from residents, businesses, and local authorities. Developing comprehensive engagement strategies, including educational programs and participatory planning processes, is crucial for fostering community support and adopting sustainable practices. Finally, considerations for scalability and replicability are essential for the broader adoption of the resource community concept. Developing modular approaches and standardized protocols for implementation could facilitate broader application across different urban contexts. By addressing these practical considerations, the resource community concept can move beyond theoretical promise to practical implementation, paving the way for more sustainable and resilient urban developments that effectively balance environmental stewardship with economic viability and social cohesion.

5.2. Transit-Oriented Mobility Concept: A City of Short Distances

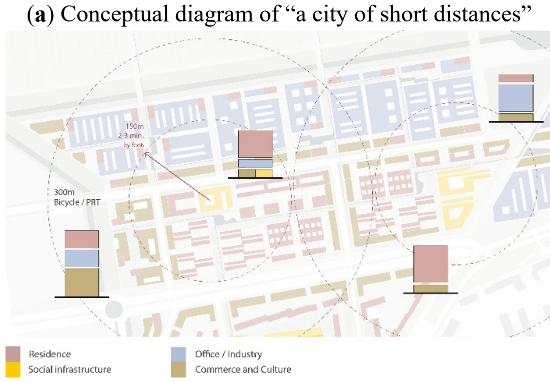
The concept of a walkable neighborhood is central to the area's sustainable urban design strategy. To achieve this while maintaining environmental integrity and optimizing land use, local public transportation, including subway and bus lines, is designed to enter the area but not pass through it. This approach strikes a balance between accessibility and environmental preservation, minimizing the impact of heavy transit infrastructure on the local ecosystem and community spaces. Within the area, an innovative Personal Rapid Transit (PRT) system is proposed to support individual transportation needs. This system represents a cutting-edge approach to urban mobility, offering personalized, on-demand transit solutions that are both efficient and environmentally friendly. Moreover, the PRT infrastructure is envisioned as a testbed for innovative experimental means of transportation, fostering technological advancement in urban mobility solutions.

At the neighborhood level, the mobility concept is predicated on two fundamental principles: the prioritization of environmentally friendly modes of transport and the implementation of buffer zones between pedestrian and vehicular spaces. This dual approach aims to create a safer, more pleasant urban environment while reducing the carbon footprint associated with local transportation. In predominantly residential areas, the shared space concept has been adopted as the primary traffic management strategy. This approach, which involves the integration of various transport modes within a single space, is combined with water elements to create multifunctional urban landscapes. A significant benefit of this design is the natural reduction of vehicle speeds due to increased driver awareness, enhancing safety for all road users without relying on traditional traffic calming measures.

The overarching urban design philosophy is anchored in the concept of "a city of short distances." This approach is rooted in the understanding that mixed-use structures bring both financial benefits and stability to neighborhoods. Consequently, all building plots are designated for mixed residential and commercial use, complete with the necessary supporting infrastructure. This strategy aims to create self-sufficient districts where daily needs can be met within walking or cycling distance, reducing reliance on motorized transportation, as shown in **Figure 9**.



(**a**) Conceptual diagram of "a city of short distances"



(**b**) Integrated urban design of "a city of short distances"

Figure 9. Conceptual diagram. (**a**) integrated urban design; (**b**) "a city of short distances".

Several urban design strategies are implemented to reduce traffic demand further and enhance the "city of short distances" concept. Firstly, a polycentric structure distributes essential amenities across multiple neighborhood centers, potentially reducing vehicle miles traveled by up to 20% [45]. Secondly, transit-oriented development (TOD) principles are prioritized around PRT stations, increasing density and mixed-use development within a 400-meter radius, which can lead to a 10–15% reduction in car ownership [60]. Additionally, a network of protected bicycle lanes and pedestrian pathways encourages active transportation, with studies showing a potential 35% increase in cycling modal share [61]. Lastly, integrating intelligent city technologies like real-time transit information optimizes existing transportation infrastructure. These strategies collectively promote healthier lifestyles while reducing traffic demand, aligning to create a self-sufficient, short-distance city.

As mentioned earlier, integrating bicycle infrastructure and the PRT further enhances the efficacy of this urban model. This allows for efficient navigation of the urban context in everyday life. Crucially, the infrastructure system is designed with universal accessibility, ensuring that all age groups and abilities are accommodated, thus promoting inclusive urban living.

Addressing the practical aspects of implementing a PRT system within a transit-oriented mobility concept, several key considerations must be taken into account. Financial barriers present a significant challenge, with infrastructure costs estimated at $10–40 million per mile [62]. As demonstrated in Masdar City, innovative funding mechanisms such as public-private partnerships can help mitigate these costs [63]. Logistical challenges arise from integrating PRT infrastructure into the urban fabric, requiring careful planning and phased implementation, as evidenced by various PRT projects worldwide [64]. Regulatory frameworks pose potential obstacles, necessitating engagement with authorities to develop supportive policies addressing safety standards and operational guidelines. The Ultra PRT system at Heathrow Airport demonstrated the importance of engaging diverse stakeholders for effective integration [64]. Finally, considerations for scalability and adaptability are essential for long-term viability, with modular designs allowing for incremental expansion and integration with emerging technologies, as seen in the Masdar City project [63]. By addressing these practical considerations, PRT systems can move beyond theoretical promise to practical realization, contributing to sustainable, efficient, and livable urban environments.

5.3. Adaptive Building Reuse

Incorporating and strengthening existing settlements and the district center is fundamental to the area's reorganization. This approach offers dual benefits: stabilizing the existing population structure while providing an economically viable transition during the transformation process. This method of urban renewal aligns with contemporary sustainable development practices, which prioritize the adaptation and improvement of existing urban fabric over wholesale redevelopment.

In both the densified existing housing estates and newly planned residential groups, a wide variety of apartment layouts is proposed to accommodate intergenerational living and diverse lifestyles, as illustrated in **Figure 10**. This diversity in housing typology is crucial for creating a resilient, inclusive community that can adapt to changing demographic needs over time. The urban structure within the former airport area is designed to follow the preserved runways, resulting in building plots oriented along a west-east axis. This design choice not only pays homage to the site's historical use but also optimizes solar exposure for new developments. Furthermore, the potential transformation of the Julius Leber barracks to the southeast into part of the urban structure exemplifies the project's commitment to adaptive reuse. The integration of this conversion area necessitates an adaptation of the access road network to align with the barracks' internal structure, demonstrating the urban design's flexibility and responsiveness to existing conditions.

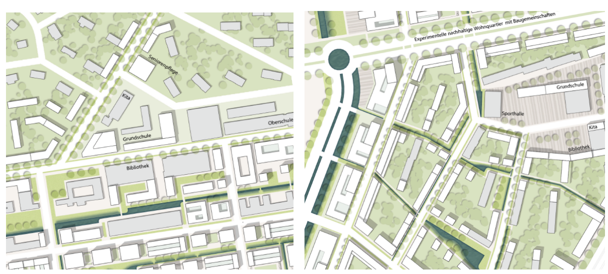


Figure 10. Densifying the existing residential area (white buildings to be fitted in among grey existing buildings reused or repurposed): northern (**left**) and southern (**right**) residential area of the former airport site.

The adaptive building reuse approach presented in this study aligns with and extends current research on sustainable urban regeneration and heritage conservation. This model builds upon the discussion, which emphasizes the importance of reusing and adapting existing structures to reduce environmental impact and preserve cultural heritage [65]. Our approach goes further by integrating adaptive reuse with diverse housing typologies and responsive urban design, simultaneously addressing multiple dimensions of urban sustainability. The preservation and repurposing of runways as organizing elements for new development echoes the findings on the benefits of adaptive reuse in urban renewal projects [31]. Combining these elements with flexible infrastructure and intergenerational living concepts, our adaptive reuse model offers a comprehensive framework for creating resilient, socially inclusive urban environments that respect historical context while meeting contemporary needs.

5.4. Synergy Effects through Parking and Shading Concept

The study site's high groundwater level challenges traditional underground parking solutions. In response, an innovative approach to parking has been developed, which addresses the parking needs and creates new opportunities for arranging private and public green spaces and a vertical utilization structure within building blocks, as seen in **Figure 11**.

Parking garages are integrated into the ground-level building blocks, extending beneath private green areas for residents. This design creates courtyards between apartment blocks, effectively separating private and public green spaces. The integration of trees planted at the parking lot level serves a dual purpose: providing natural daylight in the covered parking area and enhancing the aesthetic and environmental quality of the private courtyards. The inclusion of first-floor parking spaces facilitates deliveries to street-oriented stores, contributing to a vibrant urban atmosphere at street level. This arrangement demonstrates how careful consideration of functional requirements can be leveraged to enhance the overall urban experience.

The dense construction method employed in the design yields positive synergy effects when combined with a vertical mix of uses, particularly regarding shading and energy efficiency. For instance, offices often face overheating issues in summer are strategically placed on lower, naturally shaded levels of multi-story buildings. This passive design approach mitigates overheating without requiring additional construction work while still allowing sufficient natural light for illumination. The shaded areas created by this construction method are advantageous for retail spaces, where controlled lighting conditions are preferable for product display. This arrangement allows for reduced artificial lighting in store and business zones, contributing to energy conservation. In contrast, residential areas are positioned on upper floors to maximize natural light and heat gain, aligning with the comfort requirements of living spaces.

The economic aspects of neighborhood planning are carefully considered in the mix of uses, with service sector businesses and local supply infrastructure concentrated in first-floor zones. While workplaces and residences are typically not located in the same construction area, the continuous vertical mix of uses offers the advantage of short travel distances for residents in their daily lives. This arrangement fosters a lively street atmosphere and strengthens social networking within the neighborhood.

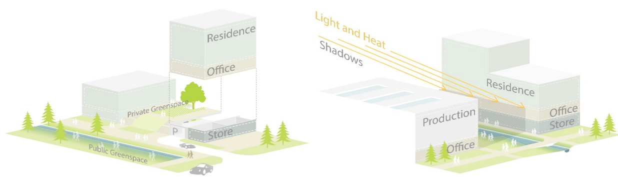


Figure 11. Synergy effects through parking and shading concept.

The innovative parking and shading concept aligns with current sustainable urban design and energy efficiency research. It builds on "climate-responsive urban design" [66], emphasizing the integration of climate considerations in urban planning. Our model enhances this by combining parking solutions, vertical mixed-use development, and passive shading strategies. The strategic placement of functions to optimize natural shading reflects findings on energy-efficient passive design [67]. This approach creates sustainable, livable urban environments that balance functional needs with energy efficiency.

6. Conclusions

This study presents a comprehensive approach to sustainable urban design, utilizing the redevelopment of Berlin's Tegel Airport area as a case study. The proposed framework integrates multiple sustainability elements, addressing the research gap identified in the introduction by providing a holistic, real-world application of sustainable urban design principles. This approach aligns with the growing recognition of the need for integrated urban planning solutions, as highlighted in work on urban landscape sustainability [3]. The research contributes significantly to the existing knowledge of sustainable urban design by demonstrating the feasibility and benefits of a truly integrated approach. By combining environmental, social, and economic aspects into a cohesive design strategy, this study bridges the gap between theoretical concepts and practical implementation. The case study of the Tegel Airport area provides a tangible example of how sustainable design principles can be applied in a large-scale urban redevelopment project, echoing the importance of such comprehensive approaches as emphasized in the former research on urban sustainability [68].

One of the key strengths of this approach is its emphasis on adaptive reuse and integration of existing infrastructure. The repurposing of the iconic terminal building and runways not only preserves the site's historical significance but also demonstrates innovative strategies for sustainable development. This aspect of the study contributes to the growing field of adaptive reuse in urban planning and offers valuable insights for similar projects worldwide. The importance of adaptive reuse in sustainable urban development has been underscored in the comprehensive review of the practice [31]. The proposed "resource community" concept and circular economy approach provide a model for optimizing resource use in urban settings. The study showcases how cities can become more self-sufficient and environmentally friendly by integrating energy production, waste management, and urban agriculture. This holistic resource management approach can reduce waste, improve economic efficiency, and enhance urban sustainability. The potential of such integrated resource management systems in urban areas has been explored in the previous research on urban metabolism [46].

The study's focus on creating a mixed-use development with a "city of short distances" concept addresses multiple aspects of sustainability. The integration of residential, commercial, and recreational spaces promotes social interaction, reduces transportation needs, and enhances residents' overall quality of life. This approach aligns with trends in urban planning that prioritize walkability and community cohesion [45]. Their meta-analysis of the built environment's impact on travel behavior proves that mixed land uses and increased walkability can significantly reduce vehicle miles traveled, contributing to more sustainable urban environments. The Tegel Airport redevelopment project's emphasis on creating a compact, mixed-use neighborhood thus reflects these evidence-based principles of sustainable urban design. The phased development strategy presented in the study offers a pragmatic approach to large-scale urban transformation. By allowing for gradual, stable growth while maintaining flexibility for future adaptations, this strategy provides a model for other cities facing similar redevelopment challenges. It demonstrates how incremental changes and adaptive planning can achieve long-term sustainability goals, a concept supported by research on adaptive planning for sustainable cities [40].

While this study provides valuable insights into sustainable urban design through the Tegel Airport redevelopment case, it has several limitations. The focus on a single case study in Berlin may limit the applicability of the proposed strategies to other urban contexts with different historical, social, and economic factors. As a proposed design rather than an implemented project, the long-term effects and success of the strategies cannot be fully assessed without actual implementation and monitoring. The study's focus on a large-scale redevelopment project may also limit its relevance to smaller urban renewal initiatives or cities with different resource constraints. Additionally, the broad scope of the research may limit the depth of analysis for each sustainability component. Lastly, the rapid pace of technological advancement in urban planning may render some proposed strategies outdated shortly. These limitations underscore the need for further research, including comparative analyses across diverse urban contexts, longitudinal studies of implemented projects, and more focused investigations into specific components of the proposed sustainable urban design model.

Comparative analyses examining the application of similar holistic approaches in diverse geographic and cultural contexts would help identify universally applicable principles and context-specific challenges. Longitudinal studies evaluating implemented sustainable urban design projects are crucial to assess their impacts and effectiveness over time. A follow-up study on the Tegel Airport redevelopment, if implemented, could provide valuable insights into the actual outcomes against projected benefits. Further research should focus on the economic viability of such projects through in-depth cost-benefit analyses comparing traditional urban development approaches with integrated sustainability models. This would help address concerns about the financial feasibility of large-scale sustainable urban design initiatives. Additionally, studies on the social impact of these projects, including potential gentrification and displacement, are needed to ensure equitable access to the benefits of improved urban environments. As technology rapidly evolves, integrating emerging technologies such as artificial intelligence and Internet of Things (IoT) devices into sustainable urban design could reveal new opportunities for creating more innovative, responsive urban environments. Further exploration of the "resource community" concept and its potential for enhancing urban sustainability and resilience in various contexts is also warranted. These research directions align with the call for more integrative and transdisciplinary approaches in urban sustainability research [23].

In conclusion, this study's holistic approach to sustainable urban design, as demonstrated through the Tegel Airport area's redevelopment proposal, offers a promising framework for creating resilient, efficient, and livable urban spaces. By integrating multiple sustainability elements and providing a real-world application, this research contributes significantly to the theoretical understanding and practical implementation of sustainable urban design principles. The findings have important implications for urban planners, policymakers, and developers, offering a model for transforming urban brownfields into vibrant, sustainable communities. This comprehensive approach to urban sustainability aligns with the vision of integrated urban development outlined in the New Urban Agenda [69], emphasizing the need for holistic strategies in addressing urban challenges. As cities worldwide continue to grow and evolve, the insights and methodologies presented in this study can serve as a valuable guide for creating more sustainable, resilient, and livable urban environments.

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Conflict of Interest

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References

[1] Meerow, S., Newell, J.P., Stults, M., 2016. Defining Urban Resilience: A review. Landscape and urban planning. 147, 38–49. DOI: https://doi.org/10.1016/j.landurbplan.2015.11.011

[2] Poerbo, H.W., 2018. Recurring Design Concepts for Resiliency in Asia. In IOP Conference Series: Earth and Environmental Science. IOP Publishing. 152(1), 012003. DOI: https://doi.org/10.1088/1755-1315/152/1/012003

[3] Ahern, J., 2013. Urban Landscape Sustainability and Resilience: the Promise and Challenges of Integrating Ecology with Urban Planning and Design. Landscape Ecology. 28, 1203–1212. DOI: https://doi.org/10.1007/s10980-012-9799-z

[4] Frantzeskaki, N., Kabisch, N., McPhearson, T., 2016. Advancing Urban Environmental Governance: Understanding Theories, Practices and Processes Shaping Urban Sustainability and Resilience. Environmental Science and Policy. 62, 1–6. DOI: https://doi.org/10.1016/j.envsci.2016.05.008

[5] Pickett, S.T., Cadenasso, M.L., McGrath, B., 2013. Resilience in Ecology and Urban Design: Linking Theory and Practice for Sustainable Cities. Springer Science and Business Media. 3, 463–489. DOI: https://doi.org/10.1007/978-94-007-5341-9

[6] Barki, J.P., Barić, A., Bach, M.P., 2022. Urban Sustainability and Urbanization: A review of Research Topics. Croatian Regional Development Journal. 3(2), 1–18. DOI: https://doi.org/10.2478/crdj-2022-0007

[7] Sharifi, A., 2021. Urban Sustainability Assessment: An Overview and Bibliometric Analysis. Ecological Indicators. 121, 107102. DOI: https://doi.org/10.1016/j.ecolind.2020.107102

[8] Sharifi, A., Murayama, A., 2013. A Critical Review of Seven Selected Neighborhood Sustainability Assessment Tools. Environmental Impact Assessment Review. 38, 73–87. DOI: https://doi.org/10.1016/j.eiar.2012.06.006

[9] Wang, A., Zhang, M., Ren, B., et al., 2023. Ventilation

Analysis of Urban Functional Zoning Based on Circuit Model in Guangzhou in Winter, China. Urban Climate. 47, 101385. DOI: https://doi.org/10.1016/j.uclim.2022.101385

[10] Yigitcanlar, T., Kamruzzaman, M., 2015. Planning, Development and Management of Sustainable Cities: A Commentary from the Guest Editors. Sustainability. 7(11), 14677–14688. DOI: https://doi.org/10.3390/su71114677

[11] Zaidan, E., Abulibdeh, A., 2021. Master Planning and the Evolving Urban Model in the Gulf Cities: Principles, Policies, and Practices for the Transition to Sustainable Urbanism. Planning Practice and Research. 36(2), 193–215. DOI: https://doi.org/10.1080/02697459.2020.1829278

[12] Zhang, M., Chen, W., Cai, K. et al., 2019. Analysis of the Spatial Distribution Characteristics of Urban Resilience and Its Influencing Factors: A Case Study of 56 Cities in China. International Journal of Environmental Research and Public Health. 16(22), 4442. DOI: https://doi.org/10.3390/ijerph16224442

[13] Seo, K.H., 2022. Cities, Technologies, and Ecology: Urban Initiatives for a Sustainable Society, Trans-Humanities. 15(1), 27–48. DOI: http://dx.doi.org/10.22901/trans.2022.15.1.27

[14] Bibri, S.E., Krogstie, J., 2017. Smart Sustainable Cities of the Future: An Extensive Interdisciplinary Literature Review. Sustainable Cities and Society. 31, 183–212. DOI: https://doi.org/10.1016/j.scs.2017.02.016

[15] Childers, D.L., Cadenasso, M.L., Grove, J.M., et al., 2015. An Ecology for Cities: A Transformational Nexus of Design and Ecology to Advance Climate Change Resilience and Urban Sustainability. Sustainability. 7(4), 3774–3791. DOI: https://doi.org/10.3390/su7043774

[16] Wang, D., Dong, L., Di, S., 2023. Data-driven Comparison of Urban Sustainability towards Sustainable Urban Development under Sustainable Development Goals (SDGs): A Review Based on Bibliometric Analysis. Frontiers in Energy Research. 11, 1168126. DOI: https://doi.org/10.3389/fenrg.2023.1168126

[17] Ayik, C., Ayatac, H., Sertyesilisik, B., 2017. A Gap Analysis on Urban Sustainability Studies and Urban Sustainability Assessment Tools. Architecture Research. 7, 1–15. DOI: https://doi.org/10.5923/j.arch.20170701.01

[18] Spiliotopoulou, M., Roseland, M., 2020. Urban sustainability: From Theory Influences to Practical Agendas. Sustainability. 12(18), 7245. DOI: https://doi.org/10.3390/su12187245

[19] Zhang, M., Tan, S., Zhang, Y., et al., 2022. Does Land Transfer Promote the Development of New-type Urbanization? New Evidence from Urban Agglomerations in the Middle Reaches of the Yangtze River. Ecological Indicators. 136, 108705. DOI: https://doi.org/10.1016/j.ecolind.2022.108705

[20] Alsayed, S.S., 2024. Urban Human Needs: Conceptual Framework to Promoting Urban City Fulfills Human Desires. Frontiers in Sustainable Cities. 6, 1395980. DOI: https://doi.org/10.3389/frsc.2024.1395980

[21] Marvuglia, A., Havinga, L., Heidrich, O., et al., 2020. Advances and Challenges in Assessing Urban Sustainability: An advanced Bibliometric Review. Renewable and Sustainable Energy Reviews. 124, 109788. DOI: https://doi.org/10.1016/j.rser.2020.109788

[22] Steiner, F., 2014. Frontiers in Urban Ecological Design and Planning Research. Landscape and Urban Planning. 125, 304–311. DOI: https://doi.org/10.1016/j.landurbplan.2014.01.023

[23] Webb, R., Bai, X., Smith, M.S., et al., 2018. Sustainable Urban Systems: Co-design and Framing for Transformation. Ambio. 47, 57–77. DOI: https://doi.org/10.1007/s13280-017-0934-6

[24] Zhang, X., He, J., Deng, Z., et al., 2018. Comparative Changes of Influence Factors of Rural Residential Area Based on Spatial Econometric Regression Model: A Case Study of Lishan Township, Hubei Province, China. Sustainability. 10(10), 3403. DOI: https://doi.org/10.3390/su10103403

[25] Elmqvist, T., Andersson, E., Frantzeskaki, N., et al., 2019. Sustainability and Resilience for Transformation in the Urban Century. Nature sustainability. 2(4), 267–273. DOI: https://doi.org/10.1038/s41893-019-0250-1

[26] Smith, M.E., 2023. How can Research on Past Urban Adaptations be Useful for Sustainability Science? Global Sustainability. 6, e4. DOI: https://doi.org/10.1017/sus.2023.2

[27] Alberti, M., McPhearson, T., Gonzalez, A., 2018. Embracing Urban Complexity. The Urban Planet: Knowledge towards Sustainable Cities. DOI: https://doi.org/10.1017/9781316647554.004

[28] Kabisch, N., Korn, H., Stadler, J., et al., 2017. Nature-based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice. Springer Nature. DOI: https://doi.org/10.1007/978-3-319-56091-5_1

[29] Sharifi, A., Yamagata, Y., 2018. Resilience-oriented Urban Planning. In: Yamagata, Y., Sharifi, A. (Eds.). Resilience-Oriented Urban Planning. Lecture Notes in Energy, vol 65. Springer: Cham, Switzerland. pp. 3–27. DOI: https://doi.org/10.1007/978-3-319-75798-8_1

[30] Wardekker, A., Wilk, B., Brown, V., et al., 2020. A Diagnostic Tool for Supporting Policymaking on Urban Resilience. Cities. 101, 102691. DOI: https://doi.org/10.1016/j.cities.2020.102691

[31] Bullen, P.A., Love, P.E., 2011. Adaptive Reuse of Heritage Buildings. Structural Survey. 29(5), 411–421. DOI: https://doi.org/10.1108/02630801111182439

[32] Yung, E.H., Chan, E.H., 2012. Implementation Challenges to the Adaptive Reuse of Heritage Buildings:

Towards the Goals of Sustainable, Low Carbon Cities. Habitat International. 36(3), 352–361. DOI: https://doi.org/10.1016/j.habitatint.2011.11.001

[33] Littke, H., Locke, R., Haas, T., 2016. Taking the High Line: Elevated Parks, Transforming Neighbourhoods, and the Ever-changing Relationship between the Urban and Nature. Journal of Urbanism: International Research on Placemaking and Urban Sustainability. 9(4), 353–371. DOI: https://doi.org/10.1080/17549175.2015.1063532

[34] Geissdoerfer, M., Savaget, P., Bocken, N.M., et al., 2017. The Circular Economy – A New Sustainability paradigm? Journal of Cleaner Production. 143, 757–768. DOI: https://doi.org/10.1016/j.jclepro.2016.12.048

[35] Prendeville, S., Cherim, E., Bocken, N., 2018. Circular Cities: Mapping Six Cities in Transition. Environmental Innovation and Societal Transitions. 26, 171–194. DOI: https://doi.org/10.1016/j.eist.2017.03.002

[36] Gravagnuolo, A., Angrisano, M., Fusco Girard, L., 2019. Circular Economy Strategies in Eight Historic Port Cities: Criteria and Indicators Towards a Circular City Assessment Framework. Sustainability. 11(13), 3512. DOI: https://doi.org/10.3390/su11133512

[37] Neuman, M., 2005. The Compact City Fallacy. Journal of Planning Education and Research. 25(1), 11–26. DOI: https://doi.org/10.1177/0739456X04270466

[38] Jenks, M., Jones, C., 2010. Dimensions of the Sustainable City. Springer Science and Business Media. 2, 1–19. DOI: https://doi.org/10.1007/978-1-4020-8647-2

[39] Miao, J.T., Phelps, N.A., 2019. The Intrapreneurial State: Singapore's Emergence in the Smart and Sustainable Urban Solutions Field. Territory, Politics, Governance. 7(3), 316–335. DOI: https://doi.org/10.1080/21622671.2018.1467787

[40] Ahern, J., 2011. From Fail-safe to Safe-to-fail: Sustainability and Resilience in the New Urban world. Landscape and urban Planning. 100(4), 341–343. DOI: https://doi.org/10.1016/j.landurbplan.2011.02.021

[41] Wolfram, M., Frantzeskaki, N., Maschmeyer, S., 2016. Cities, Systems and Sustainability: Status and Perspectives of Research on Urban Transformations. Current Opinion in Environmental Sustainability. 22, 18–25. DOI: https://doi.org/10.1016/j.cosust.2017.01.014

[42] Maas, S., Schütze, T., Hausmann, R., Erhorn, H., 2020. Lessons Learned from a Series of Monitoring Projects on New Technology Concepts for Energy Efficient Buildings in Germany. Energies. 13(11), 2948. DOI: https://doi.org/10.3390/en13112948

[43] Coaffee, J., Therrien, M.C., Chelleri, L., et al., 2018. Urban Resilience Implementation: A Policy Challenge and Research Agenda for the 21st Century. Journal of Contingencies and Crisis Management. 26(3), 403–410. DOI: https://doi.org/10.1111/1468-5973.12233

[44] Voskaki, A., Budd, T., Mason, K., 2023. The Impact of Climate Hazards to Airport Systems: a Synthesis of the Implications. Transport Reviews, 43(4), 652–675. DOI: https://doi.org/10.1080/01441647.2022.2163319

[45] Ewing, R., Cervero, R., 2010. Travel and the Built Environment: A Meta-Analysis. Journal of the American Planning Association. 76(3), 265–294. DOI: https://doi.org/10.1080/01944361003766766

[46] Pincetl, S., Bunje, P., Holmes, T., 2012. An Expanded Urban Metabolism Method: Toward a Systems Approach for Assessing Urban Energy Processes and Causes. Landscape and Urban Planning. 107(3), 193–202. DOI: https://doi.org/10.1016/j.landurbplan.2012.06.006

[47] Artmann, M., Kohler, M., Meinel, G., Gan, J., Ioja, I.-C., 2019. How Smart Growth and Green Infrastructure Can Mutually Support Each Other—A Conceptual Framework for Compact and Green Cities. Ecological Indicators. 96(1), 10–22. DOI: https://doi.org/10.1016/j.ecolind.2018.08.040

[48] Beatley, T., 2016. Biophilic Urbanism: Inviting Nature Back to Our Communities and Into Our Lives. In: Newman, P., Beatley, T., Boyer, H. (Eds.), Resilient Cities: Overcoming Fossil Fuel Dependence. Springer, Dordrecht, pp. 45–72. DOI: https://scholarship.law.wm.edu/wmelpr/vol34/iss1/6

[49] Heurkens, E., Hobma, F., 2014. Private Sector-led Urban Development Projects: Comparative Insights from Planning Practices in the Netherlands and the UK. Planning Practice and Research. 29(4), 350–369. DOI: https://doi.org/10.1080/02697459.2014.932196

[50] Zuk, M., Bierbaum, A.H., Chapple, K., et al., 2018. Gentrification, Displacement, and the Role of Public Investment. Journal of Planning Literature. 33(1), 31–44. DOI: https://doi.org/10.1177/0885412217716439

[51] Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities 'Just Green Enough'. Landscape and Urban Planning. 125, 234–244. DOI: https://doi.org/10.1016/j.landurbplan.2014.01.017

[52] Buffa, S., Cozzini, M., D'Antoni, M., 2019. 5th Generation District Heating and Cooling Systems: A Review of Existing Cases in Europe. Renewable and Sustainable Energy Reviews. 104, 504–522. DOI: https://doi.org/10.1016/j.rser.2018.12.059

[53] Roselli, C., Sasso, M., Sibilio, S., 2020. Dynamic Simulation of A Solar Electric Driven Heat Pump for AN Office Building Located in Southern Italy. International Journal of Heat and Technology. 38(1), 1–8. DOI: https://doi.org/10.18280/ijht.380101

[54] Kennedy, C., Pincetl, S., Bunje, P., 2011. The Study of Urban Metabolism and Its Applications to Urban Planning and Design. Environmental Pollution. 159(8–9), 1965–1973. DOI: https://doi.org/10.1016/j.envpol.2010.10.022

[55] Wolfram, M., 2019. Assessing Transformative Capacity for Sustainable Urban Regeneration: A Comparative Study of Three South Korean Cities. Ambio. 48(5), 478–493. DOI: https://doi.org/10.1007/s13280-018-1111-2

[56] Lenhart, J., Van Vliet, B., Mol, A.P.J., 2015. New Roles for Local Authorities in A Time of Climate Change: the Rotterdam Energy Approach and Planning as A Case of Urban Symbiosis. Journal of Cleaner Production. 107, 593–601. DOI: https://doi.org/10.1016/j.jclepro.2015.05.026

[57] Nesshöver, C., Assmuth, T., Irvine, K., et al., 2017. The Science, Policy and Practice of Nature-based Solutions: An Interdisciplinary Perspective. Science of The Total Environment. 579, 1215–1227. DOI: https://doi.org/10.1016/j.scitotenv.2016.11.106

[58] European Investment Bank, 2024. ELENA - European Local Energy Assistance. Available from: https://www.eib.org/en/products/advisory-services/elena/index.htm (cited 19 October 2024).

[59] Steen, K., Van Bueren, E., 2017. The Defining Characteristics of Urban Living Labs. Technology Innovation Management Review. 7(7), 21–33. DOI: https://doi.org/10.22215/timreview/1088

[60] Nasri, A., Zhang, L., 2014. Assessing the Impact of Metropolitan-Level, County-Level, and Local-Level Built Environment on Travel Behavior: Evidence from 19 US Urban Areas. Journal of Urban Planning and Development, 141(3), 04014031. DOI: https://doi.org/10.1061/(ASCE)UP.1943-5444.0000208

[61] Pucher, J., Dill, J., Handy, S., 2010. Infrastructure, Programs, and Policies to Increase Bicycling: An International Review. Preventive Medicine. 50(Suppl. 1), S106–S125. DOI: https://doi.org/10.1016/j.ypmed.2009.07.028

[62] Lohmann, R., Müller, K., Hessel, C., 2020. Personal Rapid Transit: A Sustainable Solution for Urban Transportation. Transportation Research Procedia. 48, 2825–2844. DOI: https://doi.org/10.1016/j.trpro.2020.08.238

[63] Mueller, K., Sgouridis, S.P., 2011. Simulation-based Analysis of Personal Rapid Transit Systems: Service and Energy Performance Assessment of the Masdar City PRT Case. Journal of Advanced Transportation. 45(4), 252–270. DOI: https://doi.org/10.1002/atr.158

[64] Schweizer, J., Pillac, V., 2021. Personal Rapid Transit: A Self-Driving Transport System for Sustainable Mobility. Sustainability.13(9), 4745. DOI: https://doi.org/10.3390/su13094745

[65] Eberhardt, L.C.M., Birgisdottir, H., Birkved, M., 2019. Life Cycle Assessment of a Danish Office Building Designed for Disassembly. Building Research and Information. 47(6), 666–680. DOI: https://doi.org/10.1080/09613218.2018.1517458

[66] Santamouris, M., Ding, L., Fiorito, F., et al., 2017. Passive and Active Cooling for the Outdoor Built Environment. Solar Energy. 154, 14–33. DOI: https://doi.org/10.1016/j.solener.2016.12.006

[67] Pacheco, R., Ordóñez, J., Martínez, G., 2012. Energy Efficient Design of Building: A Review. Renewable and Sustainable Energy Reviews. 16(6), 3559–3573. DOI: https://doi.org/10.1016/j.rser.2012.03.045

[68] Yigitcanlar, T., Teriman, S., 2015. Rethinking Sustainable Urban Development: Towards an Integrated Planning and Development Process. International Journal of Environmental Science and Technology. 12, 341–352. DOI: https://doi.org/10.1007/s13762-013-0491-x

[69] United Nations, 2017. New Urban Agenda. Available from: https://habitat3.org/wp-content/uploads/NUA-English-With-Index-1.pdf (cited 19 October 2024).