WAREHOUSE AREA TRANSFORMATION AS A DRIVER OF COMPACT CITY DEVELOPMENT: THE CASE OF WARSAW

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Abstract: One of the most significant challenges in the development of modern cities is the rational development of their space. Effective management of empty areas and other land reserves occurring in the urban fabric and their appropriate development is becoming necessary. This study presents the results of research on the identification of warehouse and industrial areas, as well as auxiliary and post-industrial regions, which have the potential to be successfully transformed towards other functions, specifically housing development. The analysis of available literature and a review of successful implementations of this type of transformation reveal that the key to success is the accessibility of transport and the availability of city services in the transformed area. In addition to accessibility, a vital factor is the size of the transformed area, allowing for the introduction of appropriate development. Thus, a suitability index was developed and calculated based on both factors for Warsaw. Subsequently, the areas with the most significant transformation potential were selected in individual city zones (functional inner city, consolidated urban and suburban). The analysis of the results and a review of the areas with the highest index value indicate the accuracy of the adopted analysis method, potentially selecting areas for transformation in other cities with high investment pressure. Thus, using the proposed methodology, the appropriate use of storage areas may limit urban sprawl and implement the idea of a compact city, which is a response to the ongoing urban crisis.

Keywords: land reserves, storage areas, compact city, urbanisation

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Introduction

In the face of increasing urbanisation and the occurrence of various types of crises, it becomes necessary to rationally develop urban space, guaranteeing the use of disused, post-industrial areas, improving the health of the population or assisting refugees or other people in an emergency (Maciejewska et al. 2022, Majewska et al. 2022).

Some of the solutions that positively affect cities are the efficient management of empty, undeveloped areas in the urban fabric and the sensible introduction of greenery through the design of green infrastructure. The need to manage land reserves in cities is increasingly being researched in Polish, European and global science units (Martinez 2017, Lopez-Pineiro 2020, Pluta 2020, Maciejewska et al. 2023).

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This need is apparent in the space and legal acts in force. In Poland, a so-called general plan of the municipality is adopted for the area of the municipality. According to the Act of 7 July 2023 amending the Act on spatial planning and development and certain other acts, the general plan may specify the following:

- areas of housing completions;
- inner-city development areas (Article 4.2).

The arrangements of the general plan shall be determined considering the conditions of spatial development of the municipality, especially the demand for new housing development in the municipality (Article 13b.7). To delimit such areas, it is necessary to identify and analyse the land reserves existing in the urban space that meet the conditions enabling easy adaptation of these areas for the purposes of locating a residential development on them or supplementing the existing development in the vicinity (Act of 27 March 2003 on spatial planning and development).

Increasingly, undeveloped land, located in fringe districts and towns adjacent to large cities, such as Warsaw, was being excluded from agricultural or forestry production. This attracted individual investors and developers (Chmielewski 2016), who were keen to take advantage of low suburban land prices and cheaper construction work. Moreover, municipal authorities allocated municipal funds to develop areas with technical infrastructure, often without respect for the spatial and natural values of these areas and most often without the participation of the local community.

Thus, empty, unused spaces have been left in the urban space – post-industrial, post-military, post-railway, post-port areas (wharves and harbours used for economic purposes) and housing estates, including those for employees of industrial plants (Hwang, Lee 2019). These spaces often remain unused for many years or even decades, despite their often attractive location and good transport accessibility (Gzell 2015).

The aim of this study was to search for optimal solutions that can help in feasibility of introducing residential development in warehouse areas, in the context of the following research questions:

1. What are the possibilities of using storage areas, located in urban sites, for residential development?
2. How to perform mathematical calculations and determine the feasibility of introducing residential development in a given area?
3. How to create recommendations and guidelines for municipalities in order to effectively manage storage areas located on their territory, in accordance with the idea of a compact and soft city?

The primary methodological objective of the study is to develop a universal index of suitability for the implementation of housing developments (building suitability index [BSI]). The applied objective is to translate the study's findings into practice by formulating recommendations and guidelines for local authorities. An additional aim is to facilitate the use of the BSI by officials and urban planners in the preparation of planning documents and in the designation of land use for specific areas.

Compared with studies conducted by other authors, an important and unique element of the article is the development of the BSI for transforming warehouses for residential purposes. The novelty of the index is that it is calculated based on how the surroundings of individual warehouses are used. The index, as defined in this way, can be helpful to cities with high investment pressure to predict which areas will change their character shortly, enabling the management of such processes. This aspect is also evident in the results of this study, where it is visible that some of the selected areas are already undergoing transformation processes. At the same time, in cities with a weaker economy, this index can help select areas whose transformation can contribute most to the revival of local businesses and communities. In the presented example, what is innovative is the index calculated for warehouse areas because most mainstream studies focus on industry.

It is also unique to conducting the analyses by functional zones of the city, delineated based on the similarity of development and land-use features. In some cases, this division is reflected in local laws and standards, such as in Warsaw. The authors emphasise the importance of functional zones in terms of identifying opportunities for further spatial development of the city (Zotic et al. 2010, de Andrade, da Cunha 2023).

In addition, the article also summarises the existing literature on the topic under study and attempts to explain the current state of its

understanding. While there is an abundance of literature on the possibilities of developing brownfield sites, this study, unlike other work, is original in that in addition to practical experiments, knowledge of transforming degraded areas was placed in the context of its usefulness for warehouse area applications. Contemporary urban planning practices around the world very rarely include these areas in transformation programmes even though they can frequently be adapted to performing a new function much more easily than typical industrial facilities.

Literature overview

The first part of the literature review deals with the importance of warehouse areas and their potential for housing development. In the second section, attention is focused on the criteria that determine the feasibility of introducing residential development in a given area, with particular reference to the availability of services. In addition, the literature overview is complemented by international examples of successful implementations and the local legal context.

According to Gasidło (1998), many factors influence the potential for transformation of a site (see Table 1).

Specific areas constituting land reserves include post-industrial and (post)warehouse areas (Tennøy et al. 2020).

The deindustrialisation and restructuring and the economic need to relocate plants and factories to the outskirts of cities have led to the emergence of vast unused areas in city centres (Artico 2017, Kazimierczak, Kosmowski 2018). Concurrently, the gradual increase in land prices, costs of production activities in cities (increase in property taxes and environmental costs) and progressive suburbanisation have forced urban planners to find ways to utilise existing building stock (Grabkowska 2018). Conversely, the expansion of urbanised areas, in particular the increasingly intensive development of economically valuable inner-city areas, has necessitated the search for opportunities to utilise existing building stock (Kusiak 2017). These factors have contributed to investor interest in post-industrial and warehouse buildings (Turek 2013).

Various areas used for industrial purposes in the past currently stand idle and represent a land reserve of the city with high potential for emergency use (Martinat et al. 2018). Unfortunately, areas of former industrial activity constitute a substantially heterogeneous group that varies in terms of the size of individual areas, proportion of open land or state of preservation of the industrial infrastructure (Van Liedekerke et al. 2013). Often, the rational management of such sites is not easy due to their problematic conditions – they are often, for example, sites with unregulated ownership status, contaminated or at risk of flooding (Rall, Haase 2011). Further development of traditional brownfields and urban warehouse sites is problematic due to the potential risks associated with their operation, such as protection of endangered species and habitats, pollution generated and acoustic climate.

Currently, several solutions have been developed to effectively manage empty, undeveloped land. These have largely been tools based

Table 1. Factors influencing the possibility of land conversion by Gasidło (1998).

Type of factor	External factors		Internal factors	
	Structural	Functional	Structural	Functional
Influencing factors	Location; Spatial structure; Diversity of use and quality of neighbouring areas Technical infrastructure; Form of ownership; Number of owners	Transport availability; Cultural patterns and social behaviour; Action on spatial planning, environmental protection and cultural assets; Use of property rights and marketing of real estate; Operation of special incentives (e.g. SEZs)	Size; Pollution; Geological structure of the area; Land cover; Spatial arrangement of development; Building index; Building intensity; Type of facilities	Erosion; Sedimentation; Power of natural succession; Behaviour of people in area (vandalism, wild conversions); Environmental risks

SEZ – special economic zone.

on brownfield sites (Cahantimur et al. 2010). The process of land use selection for brownfield sites has been extensively studied and has served as the foundation for the development of dedicated decision-making models, for example, SMARTe and SIPRIUS+ (Agostini, Vega 2009, Huysegoms, Cappuyns 2017, Hammond et al. 2021). Strategies developed in this manner tend to focus primarily on historical patterns of land use and associated pollution (Colten 1990), or on objectives related to social and economic regeneration (Williams, Dair 2007). Practical studies further demonstrate that repurposing brownfield sites contributes positively to the overall economic feasibility of redevelopment projects (Ostręga et al. 2024).

Warehouse areas are a special type of post-industrial space. In contrast to 'typical' industrial areas, they have not been the site of production processes and are therefore far less likely to exceed acceptable pollution standards (unless toxic materials have been stored there). Furthermore, warehouse areas are usually characterised by a uniform spatial structure and the provision of basic utilities (Tennøy et al. 2020). The fact that these areas have been used for warehousing development so far largely excludes the restrictions owing to the presence of unfavourable ground. Moreover, current trends in urban planning indicate a gradual move of warehousing areas to logistics centres located on the outskirts of cities, close to transport hubs (Wanfu et al. 2019).

The use of warehouse areas for residential purposes contributes to preventing further conversion of valuable agricultural and forest land, urban green space or aeration corridors (Aleha et al. 2023, Panattoni Europe 2024).

The location of a residential development on a selected site is associated with the need to meet the relevant conditions. Some of these conditions take the form of standards and indicators recommended to be met by a residential development complex (Chmielewski 2010, Dąbrowska-Milewska 2010). They include the preferred development intensity of the site, average size of the dwelling, recommended population density, average floor area ratio of the dwelling per person or the number of parking spaces.

Research indicates that the availability of services, including public transport, is crucial for the pace of investment implementation and their subsequent use (Namangaya, Kiunsi 2018). Although new residential buildings, especially those built alongside large housing estates, usually create new service points related to everyday life, their supply may initially remain insufficient. At the same time, the availability of such services significantly affects the value of real estate and, therefore, may impact the location of new investments (Kurvinen, Wiley 2019). The development of housing in the vicinity of existing areas equipped with services such as retail trade can strengthen existing service points and positively impact their offer (Powe, Gunn 2008). Good access to services can reduce the use of road transport, improve local self-sufficiency and shape patterns of travel alternative to car use (Lee, Cheng 2023), which can be crucial, especially in the early stages of the development's operation. Locating new housing estates near existing services is also crucial for creating compact cities where individual housing estates are closely connected compositionally and functionally. A large number of commercial and service facilities in one area can support their diversity, which positively impacts the economic development of the area (Yoshimura et al. 2021).

Key factors also include transport accessibility of the planned settlement area (Tiznado-Aitken et al. 2020). This accessibility is primarily concerned with the presence of essential basic services, biologically active areas and public transport stops. However, public transport stops should be considered separately. Their accessibility is significant not only because they are an important service in themselves. Public transport stops also provide access (often very convenient) to more distant service facilities or workplaces. As a result, they are natural culminating points of the estate, generating pedestrian traffic and an increased number of local interactions (Calthorpe 1993). Building and maintaining new transport lines (especially railway lines) is expensive. At the same time, for them to be as user-friendly as possible, they must maintain a high frequency of connections, which is possible if their stop surroundings are intensively used. Therefore, the surroundings of public transport stations should be developed first to ensure the sustainable development of a given estate and the entire city as well as agglomeration (Toan 2022). Most commonly, the access radius from the site in question to the surrounding areas is used for this purpose.

To increase the accuracy of the indicated calculations, network analyses are currently most commonly used (Luo et al. 2019, Sarlas et al. 2020).

The most relevant indicators take the form of standards for the location and implementation of housing developments that are regulated through local legal acts (in Poland, *inter alia*, by the Act of 5 July 2018 on facilitations in the preparation and implementation of housing investments and accompanying investments). These indicators imply, among other things, the necessity to provide for the proposed development access to a public road, water and sewage infrastructure and a power line. The standards specify the required distance from the nearest transport stop, primary school and leisure and recreation area, as well as the minimum proportion of biologically active area and the minimum number of parking spaces. Only a development that meets the stated standards can be realised in their area. Similar solutions are already in use in other countries, including the UK (Özer, Jacoby 2023), Germany (Schneider-Skalska 2004), Italy (de Biase, Losco 2018) and Canada (Tellier et al. 2024).

Table 2 gives examples of case studies of residential developments conducted on former warehouse sites, taking into account the characteristics of the area being transformed as well as the

Table 2. Case studies of residential developments on former warehouse sites.

Location	Characteristics of area	Characteristics of investment	Literature
Investments involving adaptation of existing storage facilities			
HafenCity (Speicherstadt), Hamburg, Germany	The Speicherstadt, or Granary City, is the world's largest complex of interconnected warehouses, often regarded as a symbol of Hamburg. The structures were built in 1888 of red brick in a neo-Gothic style. Facing the street is the front of the buildings and their rear part is the canal wall. The sites were listed as Hamburg's protected cultural heritage in 1991 and as a UNESCO World Heritage Site in 2015. The Speicherstadt is part of the HafenCity district.	The investments in the Speicherstadt were part of the transformation of the former port and warehouse areas into the new HafenCity district between 1999 and 2025. Some of the buildings are still used as warehouses, but the majority have been allocated to other functions, including cultural – museum and exhibition activities (International Maritime Museum, Customs Museum), as well as residential functions.	Ibáñez León and Ríos Sapa (2020), Maciejewska and Turek (2019) and Heerten (2024)
Spichlerz Gliwice, Gliwice, Poland	Part of the barracks complex of the former Prussian Provision Office, which was then used as a hospital warehouse until the early 21st century, has been adapted for housing purposes. The building was added to the Register of Historic Buildings in 2006.	The project was conducted in 2007–2008, and the original form of the building was preserved. The architectural design involved only the addition of two cuboidal staircases, higher than the main body of the building by one storey. The brick, which is the original finishing material of the external walls, was cleaned. The usable area of the adapted building is 5000 m^2.	Turek (2013) and Piegza and Rabiej (2023)
Meatpacking District, New York, USA	The Meatpacking District in New York City, located on the western edge of Manhattan, had served as an industrial district since the mid-19th century, dominated by the meat processing plants, cold storage facilities, warehouses and slaughterhouses from which it took its name. In the 1920s, the district was one of the main centres of the meat industry in New York City, but by the 1960s the district started to decline, and some of the buildings became derelict due to a change in the distribution structure of meat, dairy and agricultural products. The area has been on the National Register of Historic Places since 2003.	The area was revitalised in the 1990s, becoming a fashionable neighbourhood with luxury flats, boutiques, museums and restaurants, attracting residents and tourists. Some of the former warehouse buildings have been transformed into modern lofts. This is an example of the successful transformation of a warehouse space into a booming residential and entertainment centre.	Maquiaveli (2012) and Turner (2018)

Location	Characteristics of area	Characteristics of investment	Literature
Developments involving introduction of residential function following removal of existing development			
Barangaroo, Sydney, Australia	Barangaroo in Sydney is an area that for many years served as a port and storage centre. Beginning in the 19th century, the site was a key point for the maritime industry, where goods were stored and transhipped. During the second half of the 20th century, the area gradually declined in importance, and industrial activity was extinguished.	The revitalisation of the area started in the late 20th century and the former warehouses have been transformed into one of the most rapidly growing parts of Sydney, a thriving business, residential and leisure complex. The development is a carbon-neutral estate. A significant element in the development of the estate is the special excavation that allows basements to be located below sea level.	Badelow et al. (2014)
Nowe Żerniki, Wrocław, Poland	The area where Nowe Żerniki in Wrocław was built was partly wasteland and partly an industrial and warehouse area, typical of peripheral urban districts, before the investment. Before being transformed into a modern housing estate, the area had not been intensively built up or developed, which made it possible to realise the concept of a model housing estate from scratch, maintaining a coherent urban vision.	Nowe Żerniki in Wrocław is a modern housing estate whose concept was born as a response to the need to create a model sustainable residential area. The project started in 2011 as an initiative to prepare the residential space of Wrocław as the European Capital of Culture 2016. Nowe Żerniki combines various types of residential development with public spaces, services and green areas. The estate is distinguished by its attention to the quality of life of its residents, with a strong emphasis on ecology, infrastructure accessibility and the integration of the local community.	Lis et al. (2022)
Hammarby Sjöstad, Stockholm, Sweden	Hammarby Sjöstad (literally the town around Hammarby Lake) in the late 1980s became an area occupied by a number of semi-legal or illegal small businesses and warehouses. This caused the area to be described as a slum district. Toxic substances were found in the Hammarby Sjöstad area, deposited by the businesses operating there.	In 1995, the Stockholm authorities decided to develop the area around Lake Hammarby as part of Stockholm's bid to host the 2004 Summer Olympics. The city engaged several large private developers to make it happen. The original plan was to locate the Hammarby Sjöstad Olympic village. Despite failing to win the right to host the Games, the programme was modified to create a development in the Hammarby Sjöstad area with international leadership status in sustainable, inclusive construction and housing, with a closed water and waste recycling system for bioenergy production and renewable energy generators.	Mahzouni (2015) and Pandis Iveroth et al. (2013)

specifics of the development introduced. These estates, located in a number of countries, confirm the suitability of warehouse areas and the possibility of using them to create resident-friendly living spaces. The examples range from the situations in which warehouse buildings have been adapted for residential purposes to projects where the spatial layout of an area has been redesigned. In the first case, the result of the transformation is lofts – flats located in adapted post-industrial facilities (Piegza, Rabiej 2023).

Study area

The research covered in this study was conducted in the Polish capital, Warsaw (Fig. 1). There are many warehouse areas in Warsaw, with a decline in urban green space and a growing need for new housing developments. Warsaw covers an area of 517.2 km^2 and is divided into 18 districts.

Three functional zones have been distinguished in Warsaw (Fig. 2). This division is derived directly from the official municipal document in which it was originally established, namely the Study of Conditions and Directions for Spatial Development of the City of Warsaw. These are the functional inner city, consolidated urban and suburban zones. These zones define the nature of the development occurring in a given area and its degree of urbanisation. The location of a given area within one of the indicated functional zones influences its significance for the development of the city (Korcelli-Olejniczak 2015).

This division significantly influences local urban planning standards enacted in Warsaw in 2018. Depending on the categorisation of the area of potential development into various zones,

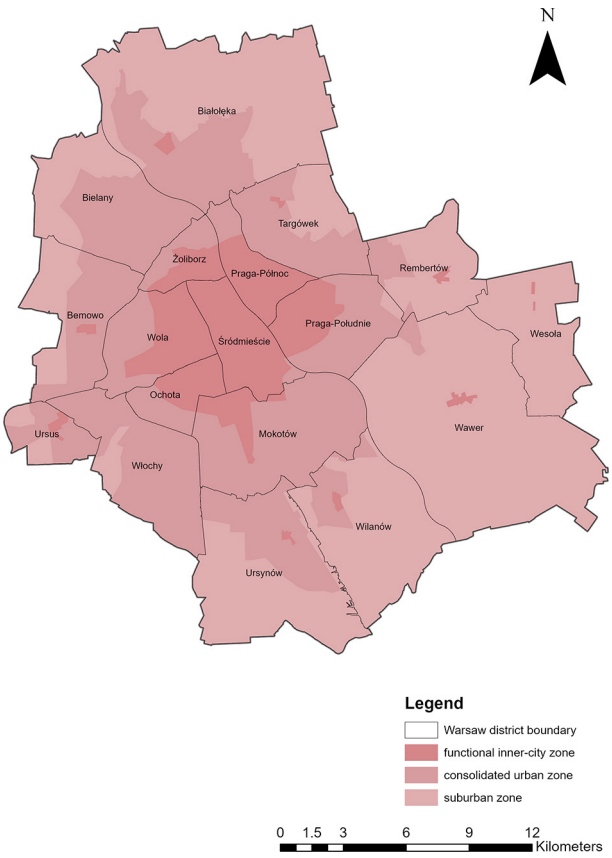

Fig. 2. Administrative division and functional zones in Warsaw.

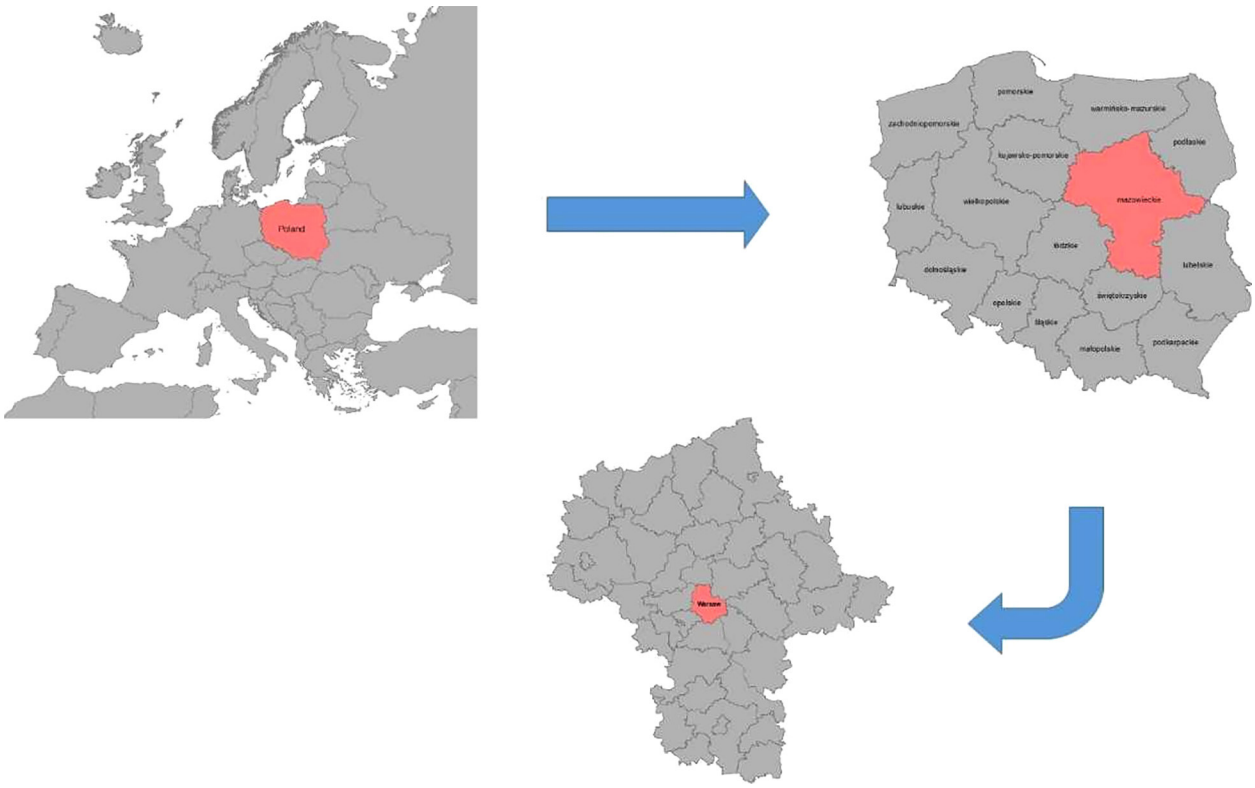

Fig. 1. Location of the study area.

different provisions apply to the transport accessibility conditions of the area. Areas located in the functional inner-city zone intended for the location of residential development should be closer to public transport stops or a primary school than similar areas located in the suburban zone. Concurrently, sites in the inner city have the opportunity to reduce the minimum shading distances for buildings and the minimum sunshine hours for rooms. Thus, inner-city areas become attractive investment locations for developers; however, the excessive density of existing buildings discourages potential residents. Consecutively, properly defined boundaries and finding areas available for development in this zone become key factors in the development of Poland's capital city (Nieroda, Gwizdak 2019). Notably, there is no definition of downtown in Polish law, and the division into the aforementioned zones is made in planning documents, based on analyses made by their authors.

No less vital for the development of Warsaw are the other two zones – the consolidated urban and suburban zones. Maintaining a balance between excessive overdevelopment, caused, among others, by the so-called housing starvation phenomenon (Antoniak-Tęskna 2020), and the rational use of space is becoming a key challenge and task for planners. Nevertheless, the gradual allocation of hitherto undeveloped areas of the suburbs for development is becoming a necessity and is inextricably linked to the spatial development of the city; however, it should be considered that large areas, simultaneously, remain in the consolidated urban zone that do not fulfil their original function. In this case, these are numerous post-industrial and warehouse areas, the proper identification of which makes it possible to identify opportunities for densification of the existing urban fabric (Chmielewski 2010).

Zoning is not the same as the administrative division, and the functional inner-city zone includes not only the central districts but also the local centres and transport nodes located within the consolidated urban zone and suburbs. Within each of the functional zones, core areas for planned development are identified. A large proportion of the areas identified as degraded (in a state of crisis) and in need of revitalisation fall into this category. These areas include (post)industrial and warehouse areas.

Materials and methods

This study analysed locations of warehouse areas in Warsaw districts and their basic parameters, and subsequently examined how the identified areas meet urban planning standards and other indicators included in the suitability index. On this basis, the possibilities of introducing residential development in warehouse areas were determined and recommendations were formulated for urban planners in this regard.

A key stage of the task was to collect the necessary data and information on available storage areas in the individual districts of the city of Warsaw. The following data sources were used for this purpose.

- BDOT Topographic Database 10 k – in terms of determining the location of currently existing storage areas and the location of roads located in these areas (validity 2023);
- Land and Building Register – with regard to the location of registered plots of land and their area (validity 2023);
- orthophotomap – in terms of defining the current land use (validity 2024);
- lists of historical land surface pollution of individual districts of the capital city of Warsaw and the register of historical land surface pollution of the General Directorate for Environmental Protection – in terms of determining potential historical pollution, the impact of which is affected by the analysed areas (validity date 2023).

QGIS software version 3.34 Prizren stable version was used for the spatial analyses and development of the resulting maps. In the final part of the analysis, results for each area were compared with each other. The study's time interval was dependent on the availability and timeliness of the statistical and spatial data used in the study.

The authors conducted their research within the functional zones of Warsaw. These were respectively:

- **Functional inner-city zone** – comprising the area of the inner city with areas of existing intensive development and areas envisaged for transformation and intensification of existing development. It constitutes an area intended for the concentration of key service functions, including public purpose investments, which, combined with residential development, will

focus on the social life of the city. For the spatial structure of the zone, historical spatial layouts are of fundamental importance. The priority in this zone is to develop public transport and ensure its high accessibility, while limiting car traffic and introducing a sustainable parking policy. The zone envisages actions aimed at increasing the attractiveness of living and investing, especially in undeveloped, degraded or inappropriately used areas.

- **Consolidated urban zone** – comprising the remaining areas of compact development, including local service centres. It is dominated by residential areas and, in the case of Central and Eastern European cities, the predominant form of development is multi-family prefabricated housing estates built in the 1970s and 1980s, as well as post-industrial and warehouse areas in need of redevelopment. The whole is complemented by urban greenery, including parks, squares and estate greenery. For spatial transformation in the zone, it is important to introduce functional diversification in mono-functional housing estates, to develop district and local centres and to adapt degraded post-industrial areas in order to create development structures with an urban character.
- **Suburban zone** – comprising the remaining areas within the administrative borders of the city, located on the outskirts. These are often areas that require subordination of the manner and forms of development to the conditions resulting from the protection of natural and environmental values. They are dominated by extensive agricultural areas with scattered residential buildings, forest complexes and enclaves of single-family housing. A considerable part of these areas supports the functioning of the city's natural system. For spatial transformation in the zone it is important to protect open areas, forest areas and areas with natural values, to stop urban sprawl and dispersed investment activities in areas not intended for development by indicating areas of planned development with the condition of ensuring compatibility between the absorptive capacity and resilience of the environment and the type and intensity of development.

Two groups of sites have been analysed – buildings defined in the Topographic Sites Database as tanks, silos and storage buildings, as well as larger farm complexes with at least one building serving as a storage. Individual buildings will primarily be earmarked for conversion to a residential function, whereas areas will be earmarked for the location of a residential development.

Those that do not meet other key criteria for suitability for development, despite good accessibility were eliminated from the database of sites since they cannot be used for this purpose. Thus, the following were excluded:

- individual warehouses within larger areas (in the database available, facilities frequently overlapped – a designated storage area was often accompanied by individual buildings within it, as identified in the second database. To avoid redundant analysis of the same facilities, individual buildings located within larger storage areas were excluded, as they were considered to be part of a broader complex by design);
- areas with an unfavourable aspect ratio (ratio of the square of the perimeter to the area);
- sites located in floodplains (where the probability of flooding is 10% and 1%);
- areas unsuitable for development with unfavourable bearing capacity and moisture content of organic soils and excessively humid;
- contaminated sites, according to the General Directorate for Environmental Protection;
- areas impossible to convert due to their functions, that is, thermal power stations, sewage treatment plants, gasworks and waterworks, as well as newly built and actively operating storage areas.

This study examined the accessibility of 10 selected basic services in the city of Warsaw (Table 3). The services selected for analysis were based on a review of the relevant literature. Previous studies have shown that the accessibility of services such as schools, kindergartens, healthcare, recreation and social services significantly influences residential satisfaction and quality of life (Goswami, Bulsara 2025). The proximity of most of these services is particularly important for vulnerable groups, such as older adults (Guida et al. 2022). The presence of public transport stations reduces travel time and increases

Table 3. Summary of the services examined.

Service	Optimum range [m]	Acceptable range [m]	Source of data on location of service points
Pre-schools	300	600	BDOT
Primary schools	600	1200	BDOT
Stations and stops of rail transport	600	1200	BDOT (rail and metro), OSM (trams)
Bus stops	300	600	OSM
Bicycle stations	300	600	OSM
Medical clinics	600	1200	BDOT
Community centres	600	1200	BDOT
Entrances to parks	600	1200	BDOT
Gyms	600	1200	OSM
Commercial facilities	300	600	OSM

access to various urban services, which is why it plays a key role in both quality of life and residential location choices (van Eck et al. 2005). Easy access to commercial facilities, including grocery stores, is fundamental to daily life. The proximity of these services allows residents to conveniently meet their basic needs (Fijałkowska 2014).

In this study, the maximum acceptable walking distance to services was set at 1200 m, corresponding to the average distance a person can walk in 15 minutes. This threshold draws upon the concept of the 15-minute city, which advocates for key urban services to be accessible within a short walk or bike ride from one's residence (Parekh 2024). However, contemporary interpretations emphasise that the 15-minute city is not a rigid spatial model but a flexible planning paradigm that should be adapted to local conditions. It encompasses a broader set of principles, including mixed-use development, inclusive digitalisation, citizen participation and the creation of self-sufficient neighbourhoods. Moreover, the model allows for variations in timeframes (e.g. 10- or 20-minute cities) and acknowledges the importance of urban density, service catchment areas and hierarchies in shaping equitable access (Willberg et al. 2023). Therefore, while the 1200-m threshold may be considered a simplification, it was adopted in this article as the most practical and justified analytical approach, enabling the construction of a coherent research model. To provide more nuanced results, an optimal access threshold was also defined, corresponding to half of the maximum acceptable distance. For kindergartens, bus stops and bike-sharing stations, the acceptable distance was further reduced due to the specific nature of these services. This approach is consistent with both local urban planning standards in the studied city and findings from the literature (Taplin, Sun 2020).

Furthermore, it was based on a network analysis with the pedestrian network built using the Topographic Facilities Database as the basis for calculations. Two range sizes were determined for each service type, namely optimal and acceptable (Table 2). For each service, a raster with a pixel size of 10 m was created in which pixels in optimal availability were assigned a value of 100, pixels in acceptable availability were assigned a value of 50 and the remaining pixels were assigned a value of 0.

In order for the multi-criteria analysis to be effective, it is necessary to give the criteria appropriate weights. For this purpose, a method based on the so-called analytic hierarchy process (AHP) developed by Saaty (1980) has been selected. With the AHP method, it is possible to determine the criteria weights more objectively than when they are determined top-down by the analyst. For this reason, it is one of the more popular methods used in GIS software (Malczewski 1999).

The calculation of the value of the criteria weights is based on a pairwise comparison operation of the importance of the criteria. In order to obtain a matrix of pairwise comparisons of criteria, the relative importance of each criterion is calculated for each criterion in the context of conducting a multi-criteria analysis. This assignment of weights is based on expert judgement, however, not a simple ranking based on the opinion of a given expert, but rather the result of pairwise comparisons. This approach makes it possible to obtain a set of weights that more accurately reflects reality, as it is generally easier to assess whether a given criterion is more important than another than to rank the entire list

Table 4. Scales for pairwise comparison (Saaty 1980).

Variables	Preferences expressed in linguistic variables
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between adjacent scale values

of criteria outright. The assessment of individual pairs was developed drawing on the team's extensive experience, informed by insights accumulated through prior research and practical engagement in the Warsaw context. By default, the AHP uses a 9-degree scale, where 1 is equal importance, 3 – moderate importance, 5 – strong importance, 7 – very strong importance and 9 – extreme importance. The remaining numbers express intermediate values, while the inverses of these numbers express the lower importance of a criterion (Table 4).

In this way, the sum of the resulting values is calculated for each criterion and then each of these values is divided by this sum. This makes it possible to sum up the relative weights for each criterion. When these are divided by the sum, the average weight for each is obtained. These weights are then multiplied by the values of the individual alternatives. In this way, a ranking of the alternatives can be obtained. The closer the value is to 1, the better the alternative, and the closer to 0, the worse.

A matrix of pairwise comparisons is consistent when the consistency ratio (CR) is less than 0.1. CR is an additional safeguarding mechanism that limits the occurrence of methodologically inconsistent results.

The analysis resulted in the weights of the criteria adopted to calculate the BSI (Table 5). The CR reached 0.095, so it can be assumed that the calculated weights are consistent. At the same time, public transport stops next to primary schools and commercial shopping facilities achieved the highest weight values, which is a logical consequence of what was described in the theoretical part.

The 10 rasters created for each criterion were subsequently multiplied by the calculated weights and finally summed. In this way, a BSI raster was created in which a pixel value of 0

Table 5. Weights of the criteria obtained with the AHP method.

Criteria	Pre-schools	Primary schools	Rail transport	Bus stops	Bicycle stations	Medical clinics	Community centres	Entrances to parks	Gyms	Commercial facilities
Pre-schools	1.00	0.33	0.20	0.20	4.00	1.00	3.00	0.25	6.00	1.00
Primary schools	3.00	1.00	0.20	0.25	5.00	3.00	6.00	2.00	7.00	3.00
Rail transport	5.00	5.00	1.00	2.00	5.00	4.00	7.00	4.00	8.00	3.00
Bus stops	0.50	4.00	0.50	1.00	4.00	4.00	6.00	3.00	8.00	2.00
Bicycle stations	0.25	0.20	0.20	0.25	1.00	0.33	3.00	0.25	4.00	0.20
Medical clinics	1.00	0.33	0.25	0.25	3.00	1.00	5.00	3.00	5.00	0.33
Community centres	0.33	0.17	0.14	0.17	0.33	0.20	1.00	0.25	4.00	0.20
Entrances to parks	4.00	0.50	0.25	0.33	4.00	0.33	4.00	1.00	5.00	0.33
Gyms	0.17	0.14	0.13	0.13	0.25	0.20	0.25	0.20	1.00	0.17
Commercial facilities	1.00	0.33	0.33	0.50	5.00	3.00	5.00	3.00	6.00	1.00
∑	16.25	12.01	3.20	5.08	31.58	17.07	40.25	16.95	54.00	11.23

Criteria	Pre-schools	Primary schools	Rail transport	Bus stops	Bicycle stations	Medical clinics	Community centres	Entrances to parks	Gyms	Commercial facilities	WEIGHT
Pre-schools	0.06	0.03	0.06	0.04	0.13	0.06	0.07	0.01	0.11	0.09	**0.07**
Primary schools	0.18	0.08	0.06	0.05	0.16	0.18	0.15	0.12	0.13	0.27	**0.14**
Rail transport	0.31	0.42	0.31	0.39	0.16	0.23	0.17	0.24	0.15	0.27	**0.26**
Bus stops	0.03	0.33	0.16	0.20	0.13	0.23	0.15	0.18	0.15	0.18	**0.17**
Bicycle stations	0.02	0.02	0.06	0.05	0.03	0.02	0.07	0.01	0.07	0.02	**0.04**
Medical clinics	0.06	0.03	0.08	0.05	0.09	0.06	0.12	0.18	0.09	0.03	**0.08**
Community centres	0.02	0.01	0.04	0.03	0.01	0.01	0.02	0.01	0.07	0.02	**0.03**
Entrances to parks	0.25	0.04	0.08	0.07	0.13	0.02	0.10	0.06	0.09	0.03	**0.09**
Gyms	0.01	0.01	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.01	**0.02**
Commercial facilities	0.06	0.03	0.10	0.10	0.16	0.18	0.12	0.18	0.11	0.09	**0.11**
∑	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**

AHP – analytic hierarchy process.

meant a location outside the area served by the primary services under study, and a value of 100 meant a location within the optimum range of all the services under study (Fig. 3). Subsequently, for each of the pre-determined storage areas, the average value of the scores in a given raster was calculated as follows:

$$BSI = \sum_{i=1}^{n} w_i x_i,\ i = 1, 2, ..., n$$

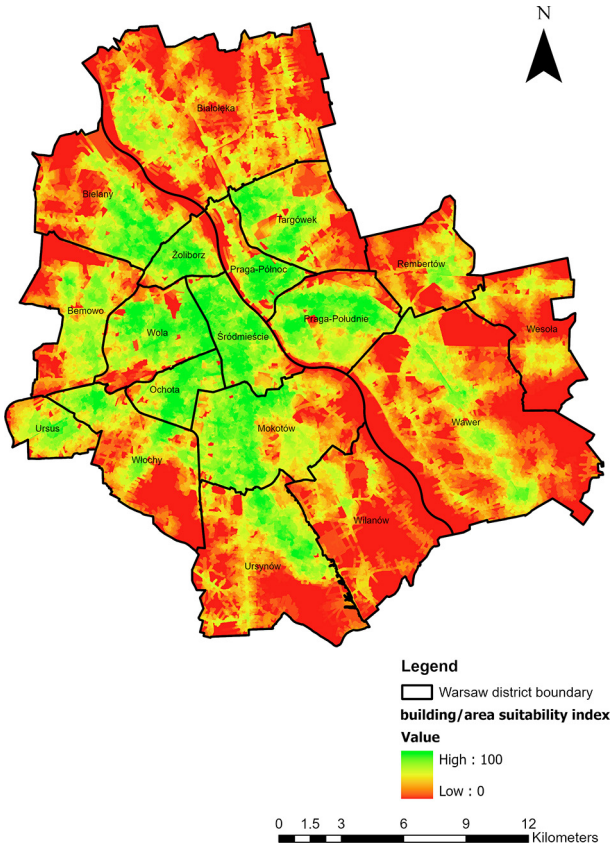

Fig. 3. Distribution of the building/area suitability index in Warsaw.

To assess the individual districts and functional zones of Warsaw in terms of the possibility of introducing residential development in warehouse areas, the following parameters were collated:

- number of buildings or storage areas located in a given district/functional zone;
- the average score of buildings or storage areas located in a given district/functional zone (x_i);
- summarised building/area suitability index (ASI), which is the sum of the scores of the areas of the individual sites.

Results

In Warsaw, a total of 153 areas and 1927 buildings with warehouse functions have been identified for possible residential use (Fig. 4). These areas and buildings are distributed in all districts and functional zones, but a clear concentration is visible in the consolidated urban zone, as well as in districts that formerly had an industrial function (Tables 6 and 7).

The largest number of buildings and warehouse areas are located in Wola, Włochy and Białołęka. In the first and last cases, these are facilities related to the former industrial history of these districts. In the case of the Włochy district, warehouses are logistical backup facilities for the airport operating within the boundaries of this district and for other, smaller plants and enterprises. The smallest number of warehouses is located in the suburban zone, where single-family housing, unmanaged green areas and some agricultural land predominate.

For buildings and storage areas, the average facility score was highest for the functional

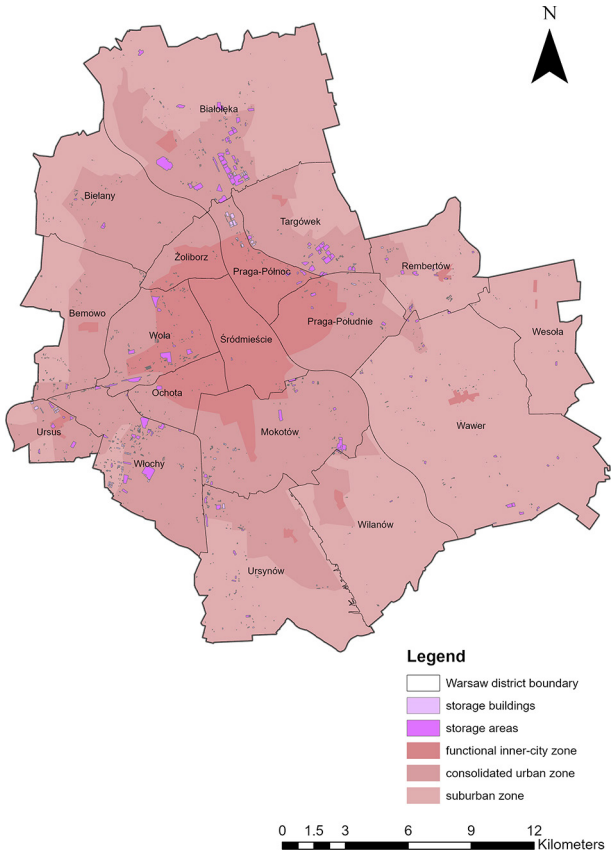

Fig. 4. Distribution of buildings and storage areas in Warsaw.

inner-city zone and correspondingly lower for the consolidated urban and suburban zones. The consolidated urban zone achieved the highest suitability index in both cases, ahead of the inner-city and suburban zones (Tables 6 and 7).

In terms of districts, the highest average facility scores were achieved by Śródmieście for buildings and Praga-Południe for warehouse areas (Figs 5 and 6). The lowest scores were awarded to Bemowo and Żoliborz (no areas). Białołęka and Włochy turned out to be the districts with the highest suitability index for areas and Włochy and Wola for warehouse buildings. The worst districts were Żoliborz and Wilanów for areas and Śródmieście and Wesoła for buildings.

Table 7. Indicators for storage areas in functional zones.

Functional area	Number of areas	Average score of areas	ASI
Functional inner city	19	66.53	3424.15
Consolidated urban	106	36.04	12635.12
Suburban	36	33.47	2038.52

ASI – area suitability index.

Table 6. Indicators for warehouse buildings in functional zones.

Functional area	Number of buildings	Average building score	BSI
Functional inner city	405	58.54	1053.11
Consolidated urban	991	39.85	3291.42
Suburban	546	32.10	868.43

BSI – building suitability index.

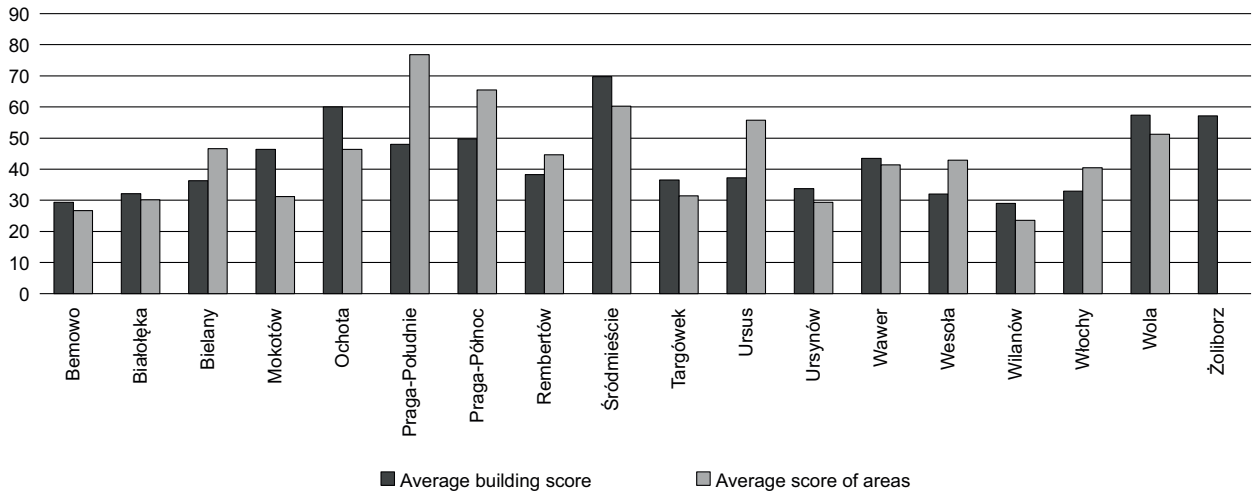

Fig. 5. Indicators for warehouse buildings in districts.

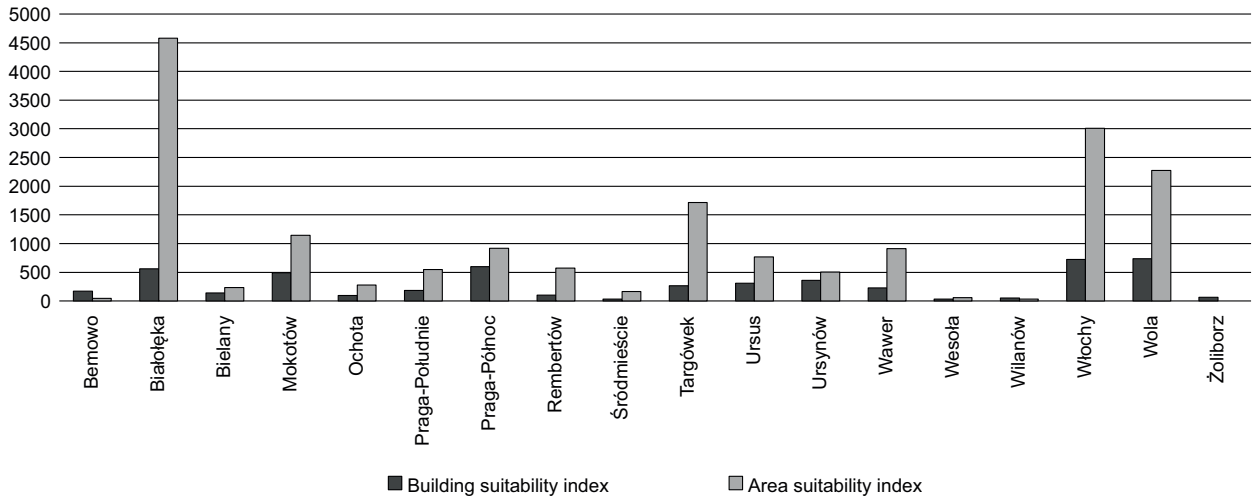

Fig. 6. Indicators for storage areas in districts.

Discussion

The results obtained show clearly visible relationships. The largest number of warehouse areas and buildings are located in the consolidated urban zone and districts with an industrial past. However, this finding does not suggest that these warehouse areas and buildings are therefore the most suitable for residential use. Indeed, the highest scores on the accessibility index were achieved by the central districts, which are part of the functional inner-city zone. Moreover, former industrial and suburban districts (e.g. Białołęka), often less well equipped in terms of services but admittedly rich in areas and warehouse buildings, achieved low average scores. Thus, there is an issue of a shortage of available areas in the inner-city zone, despite theoretically good accessibility, although there are numerous warehouses in the suburban zone, which may be difficult to introduce residential development due to their low accessibility.

An effective way of reconciling the aforementioned parameters, the number of sites with their area and their scores, was to analyse the suitability index, which is the sum of the products of the areas of individual sites and their scores. Thus, the consolidated urban zone showed the greatest potential in terms of suitability for residential development. Furthermore, it is sufficiently equipped with necessary services and rich in warehouses within its range. An example confirming the usefulness of the indicator is the fact that the highest score was achieved by Białołęka. Although it is a suburban district with extremely poor accessibility to services, Białołęka has a rich industrial and warehousing past and thus substantially high potential to introduce new development. Moreover, albeit being favourable, the aforementioned Śródmieście received one of the lowest suitability indicators because these areas are few in number and small in size compared to other districts.

Particular attention should be paid to areas with the highest scores in specific zones. In the inner-city zone, the concentration of areas with the highest scores is found in the areas located in the Wola district, north of the cross-town railway line (Fig. 7). This district was heavily affected during the Second World War, when many of its inhabitants were murdered; hence, after the war, a large part of the district acquired an industrial character. Currently, the area should be designated for the development of multifunctional urban areas. Immediately to the east of the area is the Daszyńskiego Roundabout, with the M2 metro station there and extremely intensive office development (some of the tallest office buildings in Europe are located there, including the headquarters of global corporations and international institutions such as Frontex). Conversely, in the south-western corner of the area is Warsaw West Railway Station, which is one of the main public transport hubs in the city and the most relevant railway stations in this part of Europe, serving local, regional, national and international connections. The area is extremely well served by public transport and other services and has already undergone a partial transformation towards a tertiary and residential function. The analysis demonstrates that this direction is the right one and should be continued.

In addition to the consolidated urban zone, a case-by-case analysis indicates the accuracy of the results obtained. Particularly noteworthy here is the area located parallel to Marywilska and Annopol streets (Fig. 8). There is a cluster of a dozen or so areas and industrial and warehousing facilities with the highest scores. These areas are well connected to the inner-city zone thanks to access to various types of rail transport (tram, metro and rapid urban rail). Although the availability of services is generally lower here than in the inner-city area described above, it is still at a good level, and with the addition of public services, the area could become a good place to develop the residential function that is already developing in this part of the city.

The division between storage areas and individual buildings is worth highlighting. Although the general conclusions from the analysis of the results obtained for these two groups are similar, there are some discrepancies. Warehouse buildings, not directly associated with larger areas, are found in all districts and functional zones of Warsaw. In addition, their highest number was recorded in the consolidated urban zone and the lowest in the functional centre zone. However, the fact that they are present in districts not directly linked to industry and logistics, often in locations with good accessibility, makes them attractive objects for adaptation for the residential function.

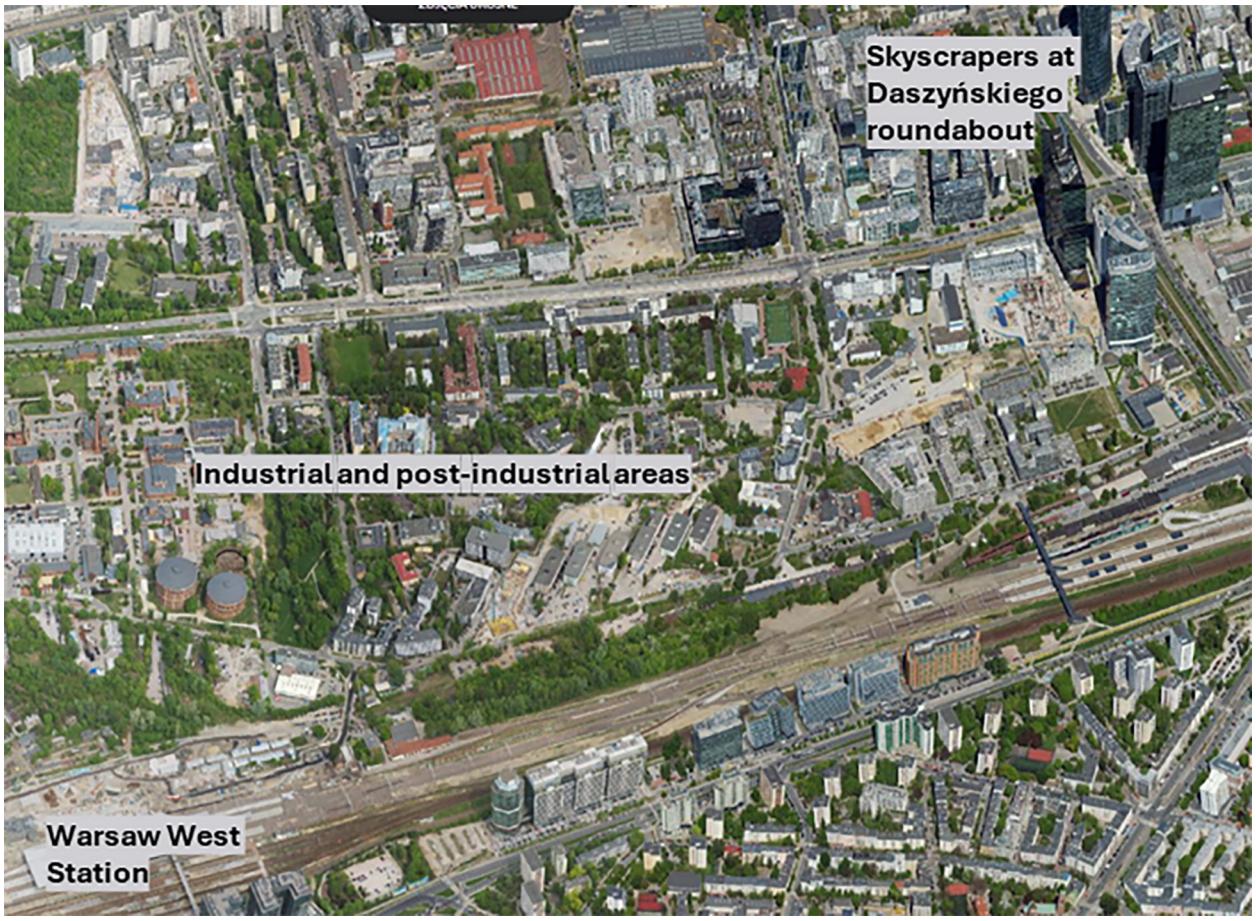

Fig. 7. Industrial and post-industrial areas in Wola from https://ukosne.um.warszawa.pl/.

In summary, when determining the location of areas and neighbourhoods rich in former warehouse areas suitable for conversion to housing, it is necessary to take into account not only the number of facilities but also their area and the availability of basic services, as well as environmental and legal constraints (Rae, Sener 2016, Novack, Hidalgo 2018, Doan, Rae 2023). It is only by taking all these factors into account that an objective assessment and analysis of the urban space is possible.

Although not directly used in the analysis conducted, a factor that remains extremely vital in the context of the possibility of introducing development into a warehouse area is its price (Dong, Hansz 2019). Land properties developed in the functional inner-city zone in Warsaw fetch far higher unit prices per square metre than similar properties located on the outskirts of the city in terms of their parameters. This makes a newly built housing estate located in the inner city extremely likely to become quickly an attractive place to live (Huang et al. 2024). However, the purchase of such land requires a significantly higher financial outlay from the potential investor. Thus, this again makes the consolidated urban zone a kind of golden mean, guaranteeing developers a profit while not having to incur large costs.

The research method applied in the article, although innovative and practical, has certain limitations that should be considered when interpreting the results. First and foremost, the analysis is based on publicly available spatial and statistical data, such as BDOT, OSM and orthophotomaps. These data sources may be outdated or incomplete, which can affect the accuracy of the findings. Moreover, the accessibility thresholds adopted in the study (e.g. 600 m, 1200 m) are generalised. Although the pedestrian network was taken into account, certain aspects – such as terrain elevation, traffic lights, other urban barriers, or the presence of greenery along walking routes (which may significantly influence accessibility during hot weather) – were not included.

Fig. 8. Industrial areas in the vicinity of Marywilska and Annopol streets from https://ukosne.um.warszawa.pl/.

Another limitation is the subjectivity involved in assigning weights to criteria using the AHP method, which is based on expert judgement. While this method is widely used and considered more objective than arbitrary weighting, the results still depend on the composition of the expert group and their perspectives and experience. The model also does not account for several important factors, such as the complexity of land ownership structures, detailed environmental contamination data, socioeconomic conditions of the surrounding area, or real estate market dynamics.

The BSI focuses primarily on spatial and functional criteria, omitting legal, social and economic aspects that, in some cases, may significantly affect the actual feasibility of implementing residential development. Additionally, the use of uniform criteria across different functional zones of the city may not fully reflect their specific characteristics. The analysis is based on the current state of land use and service availability and therefore does not consider future changes that may accompany the transformation of the studied areas.

In response to these limitations, certain barriers – such as irregular parcel shape, legal constraints, flood-prone zones and contaminated land – were identified and used to exclude unsuitable areas from consideration. Nevertheless, it was possible to determine the transformation potential of storage areas for residential development and to develop an index that effectively captures site feasibility using widely available data.

Conclusion

Given the challenges and crises of modern societies, sustainable development is a key strategy for building a sustainable future for our planet. The rational management of space, focusing on land reserves, and the public's opinions and decisions in this regard significantly influence the achievement of sustainable development goals and, consequently, living conditions today and in the future. Prompt responses to emergencies, such as the influx of refugees and internally displaced persons, allow cities to build resilience and implement sustainable development principles (Habrel et al. 2024). The evolution of urban spatial and social structure is a vital subject of research.

The analysis methodology proposed in this study, allowing the identification of the

possibilities of using warehouse areas for residential development, represents an innovative and interdisciplinary approach to spatial planning. It considers criteria relating to the area and shape of individual areas, their accessibility to the most relevant services, their location in various functional zones of the city and the limitations on the possibilities of development arising from natural conditions.

In contrast to previous studies, particular emphasis was placed on storage areas and their transport accessibility, as these sites are generally easier to adapt and may be prioritised in the initial stages of planning new residential developments. Their potential was evaluated within the city's functional zones, confirming that – particularly within the densely built-up zone – such areas offer straightforward development opportunities with minimal need for costly transformations. As a result, the findings of this study have direct practical applicability, which is often difficult to achieve through more complex models based on historical land use criteria.

The authors' objective was that the findings could be successfully applied not only in Warsaw, but in any other large or medium-sized city. This is possible by defining a suitability index and interpreting its values not only for districts, but above all for the functional zones of the city. Also, in order to make the study more common, the universal AHP method was applied when formulating the criteria, which confirmed the relevance of the accessibility of services, and public transport in particular, to the possibility of introducing a service function into an area.

While shaping the space of modern cities, the interest of a local community should be considered for achieving the sustainable development goals formulated by the UN. Indeed, the first criterion should be the creation of a city friendly to its inhabitants. This is reflected in the proposed methodology, taking the importance of transport infrastructure and functional accessibility of the area constituting the land reserve as its basis.

This study confirms the high potential for the introduction of residential development on sites and in warehouse buildings located in urban areas. Former warehouses can successfully function as land reserves and, in the long term, be used for another purpose. These areas, usually overlooked in studies, often represent space that is far more easily adaptable than non-functioning factories or landfill sites requiring considerable expenditure to clean up and tidy up.

Conclusions regarding the location of sites and warehouse buildings should be taken into account in planning documents developed at the local level (in Poland in the general plan), for example, when designating areas for housing completions and planning new settlements in a considered manner, in the vision of a compact city. Verification of the indicator's value of suitability of areas for development proposed in this study can be a vital element when setting development conditions and issuing building permits. Moreover, the verification may delimit the extent of the functional zones and inner-city development areas of the city, conducted in the relevant planning documents (Antoniak-Tęskna 2020).

Notably, such action allows sustainable planning of the spatial development of the urban structure and limits further, excessive conversion of valuable agricultural and forest land, urban green areas or aeration corridors. Given increasingly frequent natural disasters affecting cities, such as floods and droughts, which were particularly acute in 2024 in Central Europe, this becomes particularly relevant. Thus, the appropriate use of storage areas will allow the reduction of urban sprawl, the implementation of the idea of the compact city as an answer to the ever-present crisis of urbanisation (Nieroda, Gwizdak 2019) and increased resilience to inevitable climate change and natural disasters.

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Authors' contributions

ŁK: conceptualisation, investigation, methodology, resources, visualisation, writing – original draft, writing – review & editing. MI: conceptualisation, investigation, methodology, resources, writing – original draft, writing – review & editing. AM: methodology, resources, writing – review & editing, supervision.

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