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Case study

Evolution of innovative strategiesin the revitalization of post-industrial sites: A case study of the military aviation plant (WZL-4)

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Abstract: This article explores the transformation of demolition and revitalization practices over the past two decades, using the 2008 redevelopment of the Military Aviation Plant No. 4 (WZL-4) in Warsaw, Poland, as a pivotal case study. At the time, the project stood out for its forward-thinking approaches to stakeholder governance, waste management, and infrastructural integration, setting benchmarks for post-industrial redevelopment in Central Europe. This paper analyzes the WZL-4 revitalization in the context of its era – highlighting practices that were considered innovative at the time and remain relevant today – while contrasting them with contemporary strategies employed up to 2025. Drawing upon a comparative methodology and current scientific literature, the study identifies trends, innovations, and persistent challenges in the field of demolition and brownfield regeneration. It highlights key technological, procedural, and managerial advancements including BIM-based project coordination, risk-informed planning, smart monitoring, and circular economy integration. The paper contributes a dual-perspective evaluation: both retrospective and forward-looking, offering insight into how best practices have evolved and providing a roadmap for future sustainable urban redevelopment projects grounded in systemic innovation.

Keywords: project management, circular economy, demolition innovation, material recovery, public-private partnership, urban revitalization

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1. Introduction

The revitalization of post-industrial and post-military areas represents a significant challenge and opportunity for contemporary urban planning. Cities worldwide increasingly recognize the importance of redeveloping these degraded sites as part of broader sustainable urban strategies, providing new possibilities for urban growth, economic development, and environmental restoration [1–5]. Former industrial and military sites are often characterized by extensive environmental contamination, obsolete infrastructure, and fragmented land ownership, necessitating complex, multidisciplinary approaches to remediation and redevelopment [6–8]. These areas frequently require significant investments and innovative solutions, particularly given the potential risks to public health and environmental integrity posed by contaminants such as heavy metals, hydrocarbons, and hazardous chemicals.

Over the past two decades, revitalization strategies have evolved considerably, influenced by technological advancements, regulatory developments, and growing societal expectations regarding sustainability and heritage conservation. Successful revitalization projects increasingly require careful planning, use of acknowledged management methodologies [9–12], and diligent market & environment studies [13–16]. These projects also underscore the importance of a balanced approach that integrates historic preservation with modern urban needs, emphasizing cultural heritage as a crucial factor in ensuring community acceptance and long-term project sustainability [17–20].

The case of Military Aviation Plant No. 4 (WZL-4) provides an exemplary model for analyzing innovative revitalization strategies for post-industrial objects across this time frame. The site, historically significant due to its military-industrial background, faced substantial environmental and structural challenges. This study explores how adopting best practices in demolition and waste management, incorporating advanced technologies, and employing detailed environmental and structural assessments contributed to successful site revitalization in 2008. Furthermore, the WZL-4 project exemplifies how effective management strategies – many of which remain relevant today – can achieve positive outcomes while minimizing potential hazards.

By examining the evolution of demolition and revitalization practices since 2008, this paper aims to provide valuable insights for current and future urban regeneration efforts. It highlights the progression from early innovations, as exemplified by WZL-4, to the cutting-edge techniques and strategic approaches, both in development and employed in contemporary projects, offering a comprehensive perspective on the field's ongoing transformation.

2. The WZL-4 military aviation plant

The Military Aviation Plant No. 4 (WZL-4), located in Warsaw, Poland, was historically a key facility dedicated to aircraft maintenance and military aviation support. As part of Poland's Cold War-era military-industrial complex, the site housed numerous heavy-duty structures, technical workshops, and specialized equipment installations. Following the end of military operations and strategic reforms in national defense infrastructure, the WZL-4 area became a brownfield site, marked by partial abandonment and infrastructural degradation (Fig. 1).

Fig. 1. WZL-4 degradation

The site encompassed multiple hectares of land, including buildings made from reinforced concrete, steel structures, and service bunkers. Decades of military-industrial activity contributed to severe soil and groundwater contamination, particularly from petroleum derivatives, solvents, and heavy metals. Legacy hazards included residual asbestos in building insulation and unexploded ordnance risk in isolated zones. A detailed environmental assessment revealed elevated levels of hydrocarbons and chlorinated compounds in certain groundwater samples.

Urban development pressures, including housing demand and the proximity of the site to key transit corridors, triggered interest in redevelopment. WZL-4 was designated for phased demolition and revitalization, with the goal of transforming it into a mixed-use district incorporating residential, commercial, and public spaces (Fig. 2).

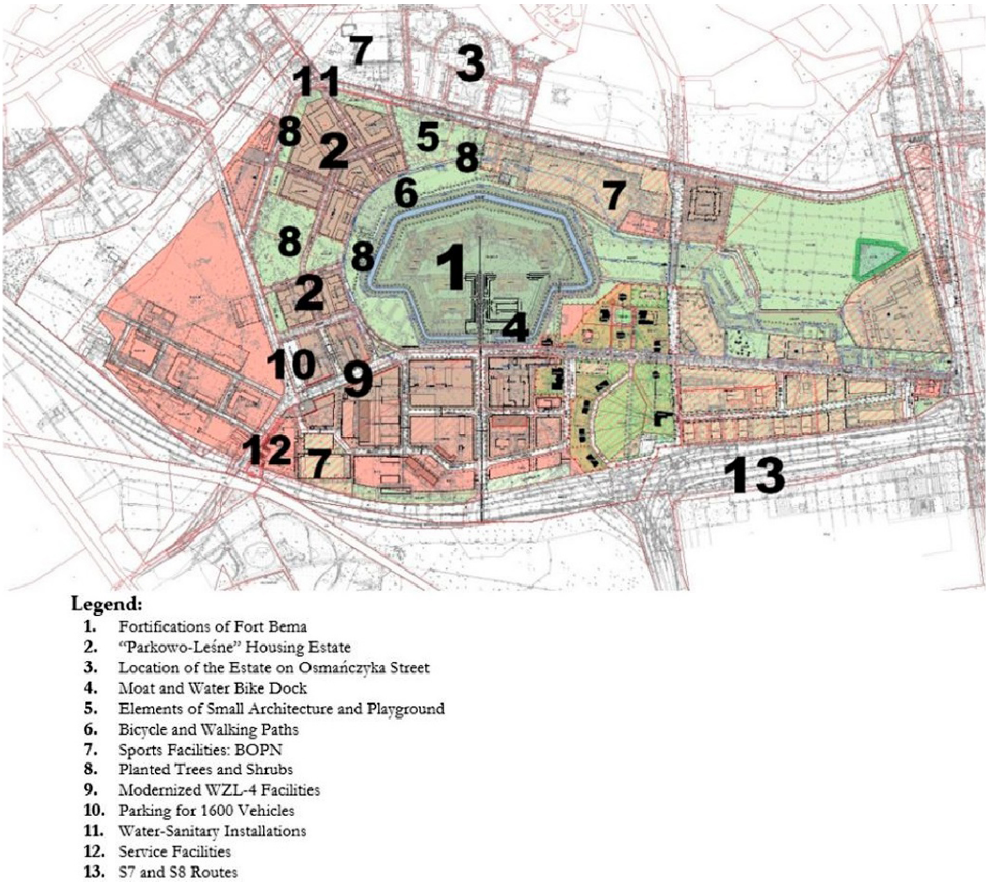


Fig. 2. Urban development plan for Fort Bema Park and Residential Complex, highlighting important installations and facilities from the perspective of the completed revitalization [5]

The redevelopment vision emphasized compatibility with local urban plans, integration with transport systems, and adherence to sustainability goals. Legal and procedural complexity formed a major component of the project. The ownership status of several parcels was ambiguous, requiring detailed cadastral and archival investigation. Environmental clearance and permitting procedures were guided by national law and EU directives, notably the Waste Framework Directive and Environmental Impact Assessment regulations. Stakeholders included municipal authorities, environmental agencies, military representatives, private contractors, and local communities.

The project's early stages involved extensive site surveys, geotechnical assessments, and the mapping of underground infrastructure. Risk-informed planning was embedded from the outset, incorporating simulation-based environmental risk projections and contingency designs. This preparatory work provided the basis for implementing innovative demolition strategies and advanced waste management practices, many of which were ahead of their time in 2008 and would still be considered progressive by today's standards.

The WZL-4 revitalization initiative was connected to the broader Fort Bema investment [5]. It was characterized by a broad, multi-actor partnership framework. The project was initiated by the Bemowo Municipality in collaboration with state-owned enterprises such as WZL-4 and private development companies. The establishment of the special purpose vehicle KR-WZLN ensured effective management of the project at every stage, streamlining coordination among public and private actors (which is not an easy task on Polish construction market [21]).

A key achievement of the public-private partnership model was the streamlining of administrative processes. The collaborative approach facilitated quicker decision-making and eliminated unnecessary bureaucratic barriers, significantly increasing the overall efficiency of the investment process. Many of these partnership-based governance principles continue to influence modern revitalization efforts.

Sustainability principles were central to the project's philosophy. Efforts focused on revitalizing the natural environment of the degraded area and increasing biologically active surfaces, which enhanced both aesthetics and biodiversity within the site. Additionally, community engagement was prioritized. The partnership model enabled local community involvement in decision-making processes, resulting in greater acceptance of the project by residents and an improved quality of life – an approach that aligns closely with today's emphasis on social sustainability.

The project employed innovative management methods through partnerships with academic institutions, allowing for the implementation of best practices in construction project management. Infrastructure modernization was another major outcome, including the replacement of worn-out facilities, improved transportation links, and enhanced public transport accessibility – all of which contributed to a better quality of life for local residents.

Financial innovation played a crucial role in the project's viability. A blended financing strategy was adopted, combining public guarantees with private investment commitments. This allowed WZL-4 to use revenues from the residential component of the development to offset its debt obligations while facilitating the construction of a jet engine test facility. This approach proved particularly valuable at a time when securing traditional bank financing was difficult – a model still referenced in modern PPP schemes.

Significant safety improvements were also achieved through the elimination of dangerous railway crossings and the construction of new transport solutions, such as flyovers, which greatly enhanced safety for local residents and reduced accident risks.

The project's innovative approach and successful execution were recognized through multiple awards, including "Construction of the Year" accolades and acknowledgments from various engineering associations. These honors highlighted the project's excellence in management, innovation, and execution, further establishing WZL-4 as a model for future post-industrial revitalization efforts and a valuable historical benchmark for analyzing the evolution of the field over the past two decades.

3. Demolition process of the WZL-4 site

3.1. Regulatory framework and initial preparations

The demolition of the WZL-4 site was initiated in the context of the planned construction of the S-8 expressway, which required the expropriation and redevelopment of a portion of the property. A detailed inventory was conducted to document the underground infrastructure, above-ground buildings, and technical equipment slated for removal.

According to Article 32 of the Polish Building Law of July 7, 1994 (Journal of Laws 2006, item 1118), in addition to a demolition design, the following were required to obtain a demolition permit:

1. Conducting an environmental impact assessment (EIA) procedure as required by environmental protection regulations.
2. Obtaining all necessary permits, approvals, or opinions from relevant authorities.

Regarding point 1: The environmental impact assessment procedure applied to particularly burdensome industrial facilities.

Regarding point 2: This requirement referred to the Waste Act of 2006, which stipulated that for demolition works generating waste, in accordance with the applicable law at the time, the waste producer was "obliged to obtain a decision approving a hazardous waste management program if they produced more than 0.1 Mg of hazardous waste annually." 1 megagram is equivalent to 1 metric ton. It is the standard SI (International System of Units) term used in legal and technical documents in Poland and the EU for large quantities of mass.

Although WZL-4 was not classified as a "particularly burdensome" plant requiring a full environmental impact assessment, waste management regulations were fully applicable. According to the Waste Act of 2006 and Article 180a of the Environmental Protection Law, demolition activities that generated hazardous waste above 1 Mg/year or other waste above 5,000 Mg/year required a formal permit. As projected waste volumes exceeded these thresholds, the contractor Radex S.A. – selected through a Ministry of Defense procurement process – secured a hazardous waste management program approval from the Marshal of the Mazowieckie Voivodeship.

3.2. Scope of demolition

The expressway project required the demolition of 13 structures, including:

1. Perimeter fences, roads, and paved yards.
2. Building 2: Carpentry workshop and vocational school gym.
3. Building 28: Engine conservation and packaging hall.
4. Building 17: Welding shop and defect isolation room.
5. Building 24: Aircraft engine warehouse and repair hall.
6. Building 25: Engine test stand facility (Fig. 3).
7. Building 26: Collector test hall.

8. Building 26a: Acoustic shielding structure.
9. Building 27: Gas reduction station.
10. Facility 48: Engine test exhaust outlet.
11. Garage buildings 45A, 45B, 45C.
12. Guard posts (elements of fencing).
13. Storage yard with a covered reinforced concrete bay.

Fig. 3. Engine test stand facility

3.3. Waste management program

A detailed “Hazardous Waste Management Program” was prepared (in accordance with the requirements of Article 20 of the Waste Act in force at that time), covering:

- A full balance of all waste streams, distinguishing hazardous from non- hazardous.
- Projected annual quantities for each waste type.
- Demolition methods aimed at minimizing waste and environmental impacts.
- Specific waste handling, recycling, and disposal procedures.

Additionally, supporting documentation and site investigations were prepared. Key documents included:

- Cost Calculation for Building Demolition at WZL-4 (by an Expert Building Consultancy Agency – Agencja Doradztwa Ekspertyz Budowlanych).
- Demolition Design (by Jarosław Olszewski M.Sc., Eng.), comprising:
  - Building inventory with photographic documentation.
  - Technical description and demolition sequence.
  - Waste management and safety plans.
  - Layout drawings for site operations and waste container placement.

According to the demolition plan, site investigations focused on several important aspects. Identifying floor sumps that had collected contaminants. Mapping areas of potential chemical contamination. Inspecting for asbestos- containing materials. Reviewing areas of past material unloading and soil contamination. Assessing sump maintenance and pre-treatment of effluents.

Laboratory analyses conducted by the Regional Environmental Inspectorate confirmed that no contamination levels exceeded regulatory thresholds (per the 2005 Regulation on Waste Disposal Criteria). These findings informed the waste separation plan and optimized the demolition workflow to prioritize hazardous waste removal and maximize material recovery.

1. The demolition sequence included:
2. Dismantling technological equipment (by the investor).
3. Dry removal of floor contaminants in industrial spaces.
4. Extraction and secure disposal of hazardous materials.
5. Dismantling underground networks.
6. Staged building demolition following a predefined sequence.
7. Designated zones for:
   a. Hazardous waste containers.
   b. Sorting recyclable waste.
   c. Non-recyclable waste collection.
8. Use of standard waste classification codes (per the EU Waste Catalogue).

A detailed forecasting of waste streams guided the Waste Management Program. The assessment covered both hazardous and non-hazardous categories.

– Hazardous waste: 35 Mg, including sludge, asbestos, tar products, and mercury-bearing materials.
– Non-hazardous waste: Over 26,000 Mg, including concrete rubble, brick rubble, road reconstruction waste, metals, wood, glass, and plastics.

This transparent and verifiable waste inventory supported logistical planning and enabled material recovery in line with circular economy principles.

4. Framework for innovation in demolition and revitalization

Innovation in the field of demolition and urban revitalization has evolved substantially since the time of the WZL-4 project in 2008. The WZL-4 project itself demonstrated forward-thinking strategies that were considered highly advanced at the time – many of which continue to serve as a foundation for today's best practices. This chapter examines both the innovations applied during the WZL-4 demolition and the contemporary advancements that have since transformed the discipline.

Innovation in the context of urban redevelopment encompasses new methods, tools, and approaches aimed at increasing efficiency, sustainability, and resilience across all project phases [22, 23]. In the case of WZL-4, innovation was integrated across technical, procedural, and social dimensions, with a focus on minimizing environmental impact and enhancing project transparency.

4.1. Selective demolition and material recovery

One of the key innovations at WZL-4 was the emphasis on selective demolition. Rather than relying on traditional mechanical methods that result in mixed waste streams, the project incorporated staged dismantling processes that allowed for the segregation of valuable materials such as metals, wood, and clean concrete. This approach improved worker safety, reduced dust emissions, and maximized material recovery – principles that align well with today's circular economy strategies.

Since 2008, selective demolition has further advanced with the use of laser scanning and 3D modeling technologies. These tools allow for precise planning of dismantling sequences, minimizing structural risks and enabling better reuse of recovered materials. The integration of Building Information Modeling (BIM) with these scanning methods has made selective demolition both more efficient and more sustainable in modern projects (Fig. 4) [24, 25].

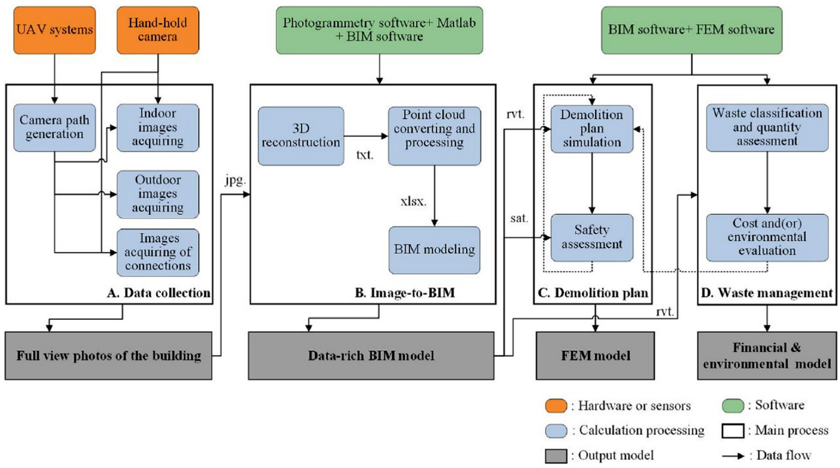


Fig. 4. The flowchart of smart building demolition and CDWM with Image-to- BIM [24]

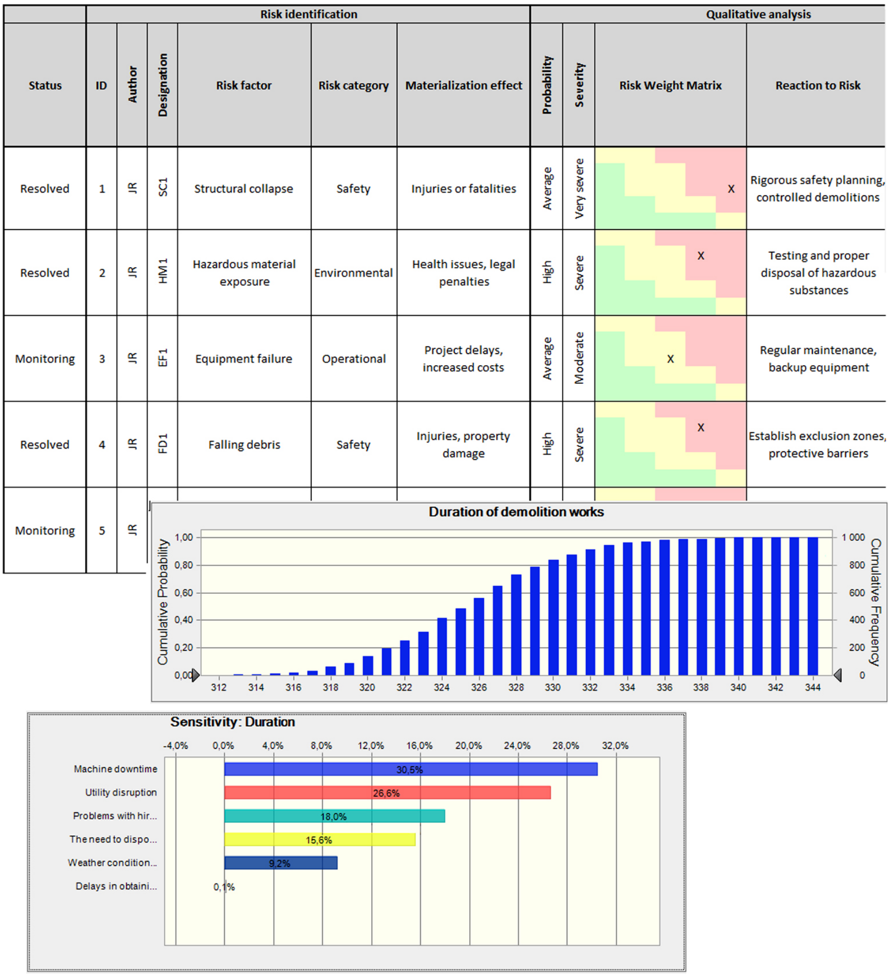
The WZL-4 demolition process was supported by thorough site investigations and contamination assessments, ensuring that hazardous materials were identified and safely removed. This early focus on environmental stewardship was ahead of its time and anticipated later trends toward integrated remediation.

Contemporary projects now employ advanced in-situ remediation techniques such as chemical oxidation, soil vapor extraction, and bioremediation to treat contaminated soils and groundwater directly on site. These methods reduce the need for large-scale excavation and off-site transport, resulting in lower carbon footprints and faster project timelines [26].

4.2. Digital tools and data integration

Digital tools can also play a pivotal role in demolition works. Building Information Modeling (BIM) can be used to integrate structural data, contamination zones, and service infrastructure, facilitating coordinated planning [27]. Risk analysis simulations – based on

Monte Carlo methods and scenario modeling – allow the project team to evaluate different intervention strategies and their potential outcomes [28]. A sample of a risk register and analysis for demolition works is presented in Fig. 5.



Risk identification							Qualitative analysis			
Status	ID	Author	Designation	Risk factor	Risk category	Materialization effect	Probability	Severity	Risk Weight Matrix	Reaction to Risk
Resolved	1	JR	SC1	Structural collapse	Safety	Injuries or fatalities	Average	Very severe	X	Rigorous safety planning, controlled demolitions
Resolved	2	JR	HM1	Hazardous material exposure	Environmental	Health issues, legal penalties	High	Severe	X	Testing and proper disposal of hazardous substances
Monitoring	3	JR	EF1	Equipment failure	Operational	Project delays, increased costs	Average	Moderate	X	Regular maintenance, backup equipment
Resolved	4	JR	FD1	Falling debris	Safety	Injuries, property damage	High	Severe	X	Establish exclusion zones, protective barriers
Monitoring	5	JR								

Fig. 5. Sample risk register and analysis fragments

The growing complexity of demolition and construction projects has elevated the need for structured, data-informed decision-making systems. Modern approaches now frequently employ Multi-Criteria Decision Analysis (MCDA), which allows planners to integrate a wide array of quantitative and qualitative factors – ranging from environmental impacts to economic efficiency and social acceptance – into a unified evaluative framework. MCDA has proven effective in identifying optimal locations for construction and demolition waste (CDW) facilities, balancing logistical, environmental, and regulatory considerations. Some of the most recent publications propose a comprehensive MCDA framework tailored to urban CDW management, highlighting the scalability of such methods even in resource-constrained cities like Dhaka [29]. In parallel, techniques such as Analytic Hierarchy Process (AHP), fuzzy logic, and GIS integration are being applied to evaluate trade-offs between demolition scenarios, particularly in assessing stakeholder priorities and environmental constraints. These tools are increasingly supported by digital platforms and BIM-integrated dashboards, enabling real-time scenario simulations and adaptive project governance. Effective decision systems also incorporate diversity management strategies, ensuring that stakeholder perspectives are considered holistically. When applied rigorously, these systems transform demolition from a reactive operational task into a forward-looking, strategic function – enhancing sustainability, transparency, and resilience in revitalization projects [30–32].

In the case of the project described, the management emphasized waste tracking and documentation systems. Additionally, it was established that for future projects, further innovations may be used. QR-coded labels could be applied to major waste streams, linking on-site materials with transport and recycling data in a centralized digital registry. Such solutions exist nowadays and provide additional transparency, traceability, and compliance with EU waste handling regulations [33].

4.3. Smart monitoring and real-time control

The WZL-4 project highlighted the importance of monitoring environmental impacts, although the tools available in 2008 were relatively limited. Today's projects employ smart monitoring systems, including drone-based images and models (Fig. 6), thermal imaging, and sensor arrays for progress monitoring, and detecting airborne particulates and noise levels. These systems enabled early detection of issues and supported evidence-based reporting to regulatory bodies and community stakeholders [34, 35].

Fig. 6. Orthophoto mosaics and 3D models showcasing progress of works [35]

4.4. Adaptive and agile project management

The WZL-4 demolition process demonstrated early examples of adaptive project management, with modular work stages and feedback loops that allowed for responsive adjustments based on site conditions. Such an approach was particularly critical in enabling project success within the highly challenging Polish public-private partnership (PPP) environment. The use of adaptive project management allowed the WZL-4 team to navigate evolving regulatory frameworks, coordinate diverse public and private interests, and maintain project momentum despite administrative uncertainties. This flexibility proved to be a key enabler of trust among partners and ensured that the project could deliver on its ambitious goals in a setting where rigid, traditional project management approaches might have failed.

In modern practice, agile project management principles – originally developed in the software industry – are being adapted for complex construction and demolition projects. This approach promotes iterative planning, stakeholder collaboration, and flexibility, enabling project teams to manage uncertainty and change more effectively [36].

5. Discussion and conclusions

Several principles demonstrated at WZL-4 remain cornerstones of sustainable demolition today. The project's focus on material recovery, risk-informed planning, and adaptive project management continues to inform modern practice. What has changed significantly is the depth of digital integration and the sophistication of tools available to project teams.

Over the past 17 years, the field of demolition and urban revitalization has undergone significant transformation. The integration of advanced digital tools, such as BIM and real-time monitoring systems, has enhanced the precision and efficiency of demolition processes. Environmental remediation technologies have evolved, allowing for more effective in-situ treatment of contaminants. Additionally, the rise of circular economy principles has shifted project priorities toward maximizing material reuse and minimizing waste.

One of the most valuable lessons from WZL-4 was the importance of stakeholder-driven governance. The project demonstrated that trust-building, transparency, and responsiveness to community concerns can significantly enhance project outcomes and public acceptance. Today, stakeholder engagement has become even more sophisticated, often leveraging digital participation platforms, community dashboards, and immersive visualization tools to ensure inclusive dialogue. The Public-Private Partnership (PPP) model used in WZL-4 also remains highly relevant, providing a framework for balancing commercial imperatives with public interest.

Looking forward, the future of demolition and urban revitalization will likely be shaped by further integration of artificial intelligence, machine learning, and automation. Predictive models will enable even more accurate risk assessment, schedule optimization, and resource allocation. Advances in robotic demolition and automated material sorting are already emerging, promising to enhance both safety and material recovery rates.

Additionally, the growing emphasis on net-zero construction and life-cycle carbon analysis is pushing the industry to adopt even more rigorous sustainability benchmarks. Demolition will increasingly be viewed not as an endpoint but as a critical enabler of circular, regenerative urban development.

As urban areas continue to evolve, the need for sustainable, efficient, and socially responsive demolition practices will only grow. The WZL-4 experience serves as both a historical benchmark and an ongoing source of inspiration for the next generation of revitalization projects. The WZL-4 project offers a compelling case study for understanding the trajectory of innovation in demolition and urban revitalization

References

[1] F. Camerin and R. Córdoba Hernández, „The disposal of military sites in Spain today. Challenges and limitations towards a sustainable urban development", in *Proceedings of the 2nd Conference on Future Challenges in Sustainable Urban Planning & Territorial Management*. Cartagena, Spain: Technical University of Cartagena (UPCT), 2024, doi: 10.31428/10317/13644.

[2] H.A. Eiselt, „Locating landfills-optimization vs. reality", *European Journal of Operational Research*, vol. 179, no. 3, pp. 1040–1049, 2007, doi: 10.1016/j.ejor.2005.11.039.

[3] Ł. Kuzak, C. Gabryel, A. Maciejewska, and J. Sobieraj, „Potentials and opportunities for revitalisation of post-harbour areas based on the Port of Zeran in Warsaw case study", *Archives of Civil Engineering*, vol. 70, no. 2, pp. 195–214, 2024, doi: 10.24425/ace.2024.149859.

[4] K. Perkov and T. Jukić, „Historical Development of Military Sites and Their Impact on Urban and Rural Land Use in the European Context: Exploring the Social Context and Spatial Footprint", *Prostor*, vol. 31, no. 2, pp. 248–261, 2023, doi: 10.31522/p.31.2(66).9.

[5] J. Sobieraj and D. Metelski, „Innovative Approaches to Urban Revitalization: Lessons from the Fort Bema Park and Residential Complex Project in Warsaw", *Buildings*, vol. 15, no. 4, art. no. 538, 2025, doi: 10.3390/buildings15040538.

[6] M.B. Glintić, „Revitalization of military brownfields in Eastern and Central Europe", *Strani Pravni život*, vol. 2015, no. 4, pp. 123–136, 2015.

[7] N. Leshchenko and D. Gulei, „Complex revitalization of historically formed industrial territories in Kyiv in post-war recovery", *Journal of Architecture and Urbanism*, vol. 48, no. 1, pp. 1–10, 2024, doi: 10.3846/jau.2024.19337.

[8] A. Maciejewska, Ł. Kuzak, J. Sobieraj, and D. Metelski, „The impact of opencast lignite mining on rural development: a literature review and selected case studies using desk research, panel data and GIS-based analysis", *Energies*, vol. 15, no. 15, art. no. 5402, 2022, doi: 10.3390/en15155402.

[9] M.C. Aceves and M. Fuamba, „Methodology for selecting best management practices integrating multiple stakeholders and criteria. Part 2: case study", *Water*, vol. 8, no. 2, art. no. 56, 2016, doi: 10.3390/w8020056.

[10] A.E. Punt, D.S. Butterworth, C.L. de Moor, J.A.A. De Oliveira, and M. Haddon, „Management strategy evaluation: best practices", *Fish and Fisheries*, vol. 17, no. 2, pp. 303–334, 2016, doi: 10.1111/faf.12104.

[11] J. Sobieraj, D. Metelski, and P. Nowak, „PMBoK vs. PRINCE2 in the context of Polish construction projects: Structural Equation Modelling approach", *Archives of Civil Engineering*, vol. 67, no. 2, pp. 551–579, 2021, doi: 10.24425/ace.2021.137185.

[12] J. Sobieraj and D. Metelski, „Identification of the key investment project management factors in the housing construction sector in Poland", *International Journal of Construction Management*, vol. 23, no. 1, pp. 1–12, 2023, doi: 10.1080/15623599.2020.1844855.

[13] J.A. Bamgbade, A.M. Kamaruddeen, and M.N.M. Nawi, „Towards environmental sustainability adoption in construction firms: An empirical analysis of market orientation and organizational innovativeness impacts", *Sustainable Cities and Society*, vol. 32, pp. 486–495, 2017, doi: 10.1016/j.scs.2017.04.015.

[14] Ö. Çimen, „Construction and built environment in circular economy: A comprehensive literature review", *Journal of Cleaner Production*, vol. 305, art. no. 127180, 2021, doi: 10.1016/j.jclepro.2021.127180.

[15] J. Sobieraj and D. Metelski, „Application of the Bayesian New Keynesian DSGE Model to Polish Macroeconomic Data", *Engineering Economics*, vol. 32, no. 2, pp. 140–153, 2021, doi: 10.5755/j01.ee.32.2.27214.

[16] J. Sobieraj and D. Metelski, „Private renting vs. mortgage home buying: case of British housing market – A Bayesian network and directed acyclic graphs approach", *Buildings*, vol. 12, no. 2, art. no. 189, 2022, doi: 10.3390/buildings12020189.

[17] F. Di Maddaloni and L. Sabini, „Very important, yet very neglected: Where do local communities stand when examining social sustainability in major construction projects?", *International Journal of Project Management*, vol. 40, no. 7, pp. 778–797, 2022, doi: 10.1016/j.ijproman.2022.08.007.

[18] A. Nicał, „Outlook for the implementation of selected Ambient Assisted Living concepts for panel building", *Technical Transactions*, vol. 2017, no. 4, pp. 123–130, 2017, doi: 10.4467/2353737XCT.17.053.6364.

[19] A.K. Nicał, „Selected technical solutions in construction for elderly people in Poland", *Archives of Civil Engineering*, vol. 62, no. 4/1, pp. 87–98, 2016, doi: 10.1515/ace-2015-0099.

[20] J.A.E. Nielsen, K. Stavrianakis and Z. Morrison, „Community acceptance and social impacts of carbon capture, utilization and storage projects: A systematic meta-narrative literature review", *PLoS ONE*, vol. 17, no. 8, art. no. e0272409, 2022, doi: 10.1371/journal.pone.0272409.

[21] A. Foremny, J. Kulejewski, H. Anysz, and A. Nicał, „Collusion and bid rigging in the construction industry: case studies from Poland", in *Proceedings of the Creative Construction Conference 2018*, M.J. Skibniewski and M. Hajdu, Eds. Budapest: Diamond Congress Ltd., 2018, pp. 822–829, doi: 10.3311/CCC2018-107.

[22] N. Murtagh, L. Scott, and J. Fan, „Sustainable and resilient construction: Current status and future challenges", *Journal of Cleaner Production*, vol. 268, art. no. 122264, 2020, doi: 10.1016/j.jclepro.2020.122264.

[23] J. Sobieraj and D. Metelski, „Economic determinants of total factor productivity growth: The Bayesian modelling averaging approach", *Entrepreneurial Business and Economics Review*, vol. 9, no. 4, pp. 147–171, 2021, doi: 10.15678/EBER.2021.090410.

[24] X. Hu, Y. Zhou, S. Vanhullebusch, R. Mestdagh, Z. Cui, and J. Li, „Smart building demolition and waste management frame with image-to-BIM", *Journal of Building Engineering*, vol. 49, art. no. 104058, 2022, doi: 10.1016/j.jobe.2022.104058.

[25] P. Nowak, M. Książek, M. Draps, and J. Zawistowski, „Decision making with use of building information modeling", *Procedia Engineering*, vol. 153, pp. 519–526, 2016, doi: 10.1016/j.proeng.2016.08.177.

[26] L.B. Jugnia, D. Manno, K. Drouin, and M. Hendry, „In situ pilot test for bioremediation of energetic compound-contaminated soil at a former military demolition range site", *Environmental Science and Pollution Research*, vol. 25, no. 20, pp. 19436–19445, 2018, doi: 10.1007/s11356-018-2115-y.

[27] B. Nikmehr, M.R. Hosseini, J. Wang, N. Chileshe, and R. Rameezdeen, „BIM- based tools for managing construction and demolition waste (CDW): A scoping review", *Sustainability*, vol. 13, no. 15, art. no. 8427, 2021, doi: 10.3390/su13158427.

[28] D.J. Patel, S.A. Ponnana, D.A. Patel, and M.B. Patel, „Development of a framework for risk assessment in building demolition works", *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, vol. 15, no. 3, art. no. 04523016, 2023, doi: 10.1061/JLADAH.LADR-931.

[29] D.S.A. Rayhan and I.U. Bhuiyan, „A framework for evaluation of construction and demolition waste management alternatives using MCDA techniques in the context of Dhaka City", *International Journal of Construction Management*, vol. 25, no. 4, pp. 481–493, 2025, doi: 10.1080/15623599.2024.2337083.

[30] G. Banias, C. Achillas, C. Vlachokostas, N. Moussiopoulos, and S. Tarsenis, „Assessing multiple criteria for the optimal location of a construction and demolition waste management facility", *Building and Environment*, vol. 45, no. 10, pp. 2317–2326, 2010, doi: 10.1016/j.buildenv.2010.04.016.

[31] M. Książek and P. Nowak, „Diversity management aspects in construction", *Acta Scientiarum Polonorum. Architectura*, vol. 16, no. 2, pp. 63–68, 2017, doi: 10.22630/ASPA.2017.16.2.08.

[32] P. Nowak and M. Skłodkowski, „Multicriteria analysis of selected building thermal insulation solutions", *Archives of Civil Engineering*, vol. 62, no. 3, pp. 137–148, 2016, doi: 10.1515/ace-2015-0088.

[33] A. Dervishaj, J.H. Vargas, and K. Gudmundsson, „Enabling reuse of prefabricated concrete components through multiple tracking technologies and digital twins", in *Proceedings of 2023 European Conference on Computing in Construction and the 40th International CIB W78 Conference*. Sint-Niklaas, Belgium: European Council for Computing in Construction, 2023, doi: 10.35490/EC3.2023.220.

[34] Y. Jiang, et al., „Automatic volume calculation and mapping of construction and demolition debris using drones, deep learning, and GIS", *Drones*, vol. 6, no. 10, art. no. 279, 2022, doi: 10.3390/drones6100279.

[35] D. Unger, V. Williams, E. Ironsmith, D. Kulhavy, I.K. Hung, and Y. Zhang, „Comparing Remote Sensing Methodologies to Evaluate the Impact of Building Demolition using Drone Imagery", *International Journal of Geospatial and Environmental Research*, vol. 12, no. 1, 2025.

[36] K.N. Mohammed and S.C. Karri, „An analytical approach in usage of agile methodologies in construction industries-A case study", *Materials Today: Proceedings*, vol. 33, Part 1, pp. 475–479, 2020, doi: 10.1016/j.matpr.2020.05.045.

Ewolucja innowacyjnych strategii w rewitalizacji terenów poprzemysłowych: Studium przypadku Wojskowych Zakładów Lotniczych Nr 4

Słowa kluczowe: gospodarka cyrkularna, innowacje w rozbiórkach, partnerstwo publiczno-prywatne, rewitalizacja miejska, zarządzanie projektami, odzysk materiałów

Streszczenie:

Rozbiórki obiektów budowlanych oraz rewitalizacja terenów poprzemysłowych i powojskowych należą obecnie do kluczowych zagadnień współczesnego planowania przestrzennego i inżynierii miejskiej. W warunkach coraz większego zurbanizowania przestrzeni, ograniczonych zasobów gruntów oraz rosnących wymagań środowiskowych i społecznych, niezbędne staje się wdrażanie nowoczesnych i zrównoważonych strategii zagospodarowania zdegradowanych obszarów. Celem niniejszego artykułu jest przedstawienie ewolucji strategii rozbiórkowych i rewitalizacyjnych na przestrzeni lat 2008-2025, na przykładzie inwestycji przeprowadzonej na terenie Wojskowych Zakładów Lotniczych Nr 4 (WZL-4) w Warszawie. Studium przypadku projektu zrealizowanego w 2008 roku pozwala przeanalizować praktyki, które już wówczas wykazywały cechy innowacyjności, a niektóre z nich nadal stanowią istotny punkt odniesienia dla współczesnych rozwiązań. Projekt WZL-4 obejmował kompleksową rozbiórkę infrastruktury przemysłowej zlokalizowanej na części terenu przeznaczonego pod budowę trasy ekspresowej S8. Inwestycja charakteryzowała się zastosowaniem selektywnej rozbiórki, szczegółowego planowania gospodarki odpadami, a także adaptacyjnego podejścia do zarządzania projektem. Wprowadzono wówczas podział prac na etapy, umożliwiający bieżące reagowanie na zmieniające się uwarunkowania terenowe, środowiskowe i formalno-prawne. Przyjęto również model zarządzania oparty na współpracy z licznymi interesariuszami, co w warunkach rodzącego się rynku partnerstwa publiczno-prywatnego (PPP) w Polsce stanowiło szczególne wyzwanie. W artykule wskazano, że wiele z zastosowanych w 2008 roku praktyk wyprzedzało standardy tamtego okresu. Dotyczy to m.in. podejścia do odzysku materiałów, wczesnej identyfikacji i bezpiecznego usuwania odpadów niebezpiecznych, a także uwzględnienia aspektów środowiskowych w planie rozbiórki. Pomimo braku szerokiego zastosowania cyfrowych narzędzi planistycznych, projekt wyróżniał się wysokim stopniem przygotowania dokumentacyjnego oraz wykorzystaniem danych przestrzennych do lokalizacji kontenerów i stref roboczych. Kolejne części artykułu prezentują, w jaki sposób podejście do rewitalizacji uległo zmianie w ciągu ostatnich 17 lat. Szczególny nacisk położono na integrację nowych technologii: modelowanie informacji o budynku (BIM), cyfrowe systemy śledzenia odpadów, monitoring środowiskowy w czasie rzeczywistym, wykorzystanie danych z czujników i obrazowania dronowego. Współczesne projekty coraz częściej bazują również na zintegrowanych systemach wspomagania decyzji – m.in. wielokryterialnej analizie decyzyjnej (MCDA), hierarchicznej analizie AHP czy symulacjach scenariuszowych (Monte Carlo). Pozwalają one zrównoważyć cele środowiskowe, ekonomiczne i społeczne, przy jednoczesnym zarządzaniu ryzykiem i niepewnością. Narzędzia te, zintegrowane z platformami BIM i bazami danych

GIS, umożliwiają opracowanie dynamicznych modeli decyzyjnych i bardziej efektywne zarządzanie procesem inwestycyjnym. Analizując przypadek WZL-4 w kontekście obecnych standardów, autorzy wskazują także na zmiany w modelach zarządzania projektami rewitalizacyjnymi. Oprócz digitalizacji, współczesne podejścia coraz częściej czerpią z metodyk zwinnych (agile), bazujących na iteracyjnym planowaniu, regularnym feedbacku i zaangażowaniu interesariuszy na każdym etapie projektu. Elementy te pojawiły się w zalążkowej formie już w 2008 roku na WZL-4 i przyczyniły się do sukcesu projektu – pomimo złożonego kontekstu formalno-prawnego oraz technicznego. Zakończenie artykułu stanowi podsumowanie zmian, jakie zaszły w podejściu do rewitalizacji terenów poprzemysłowych i wojskowych. Wskazano kierunki dalszego rozwoju branży, w tym automatyzację demontażu, projektowanie z myślą o przyszłym demontażu (DfD), a także konieczność włączania narzędzi śledzenia śladu węglowego i analizy cyklu życia (LCA). Zidentyfikowano również bariery implementacyjne, takie jak niski poziom integracji technologii w sektorze MŚP, ograniczony dostęp do specjalistycznych danych środowiskowych, a także niewystarczające procedury koordynacyjne na linii inwestor-gmina-społeczność lokalna. Studium przypadku WZL-4 pokazuje, że nawet w warunkach ograniczeń technologicznych i instytucjonalnych możliwe jest wdrożenie rozwiązań, które pozostają aktualne po kilkunastu latach. Projekt ten może być uznany za punkt odniesienia zarówno w kontekście dziedzictwa inżynieryjnego, jak i dla współczesnych badań nad zrównoważoną transformacją przestrzeni miejskiej.

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