



cogitatio

URBAN PLANNING

Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse

Edited by Liam James Heaphy and Philip Crowe

Volume 10

2025

Open Access Journal

ISSN: 2183-7635



Urban Planning, 2025, Volume 10

Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse

Published by Cogitatio Press

Rua Fialho de Almeida 14, 2º Esq.,

1070-129 Lisbon

Portugal

Design by Typografia®

<http://www.typografia.pt/en/>

Cover image: © Liam James Heaphy

Academic Editors

Liam James Heaphy (University of Galway)

Philip Crowe (University College Dublin)

Available online at: www.cogitatiopress.com/urbanplanning

This issue is licensed under a Creative Commons Attribution 4.0 International License (CC BY). Articles may be reproduced provided that credit is given to the original and *Urban Planning* is acknowledged as the original venue of publication.

Table of Contents

Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse

Liam James Heaphy and Philip Crowe

Heritage in a Circular Economy: Integrating Conservation, Resource Management, and Community Engagement

Johannes Warda, Georg Schiller, and Robert Knippschild

Microclimate Assessment and Outdoor Human Comfort Enhancement of a Historic Village in Sardinia, Italy

Giulia Cherchi, Alessandro Santus, Donatella Rita Fiorino, and Simone Ferrari

Sustainable Futuristic Energy Scenarios for Low-Carbon Industrial Heritage: Green Adaptive Reuse of Karaj Iron Foundry

Farzaneh Gharaati, Mohammadjavad Mahdavinejad, Martin Meyer, and Tatsuyoshi Saijo

Sustainable Heritage Buildings: The Impact on Heritage Values, Energy Performance, and CO₂ Emissions

Maarten Vieveen, Aron Banninga, Tamizhselvan Munuswamy, and Tineke van der Schoor

Zero-Emission and Zero Demolition: Promoting Conservation Interests Through the Implementation of the Energy Performance of Buildings Directive

Anna Donarelli

Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse

Liam James Heaphy ¹  and Philip Crowe ² 

¹ Irish Centre for High-End Computing, University of Galway, Ireland

² School of Architecture, Planning and Environmental Policy, University College Dublin, Ireland

Correspondence: Liam James Heaphy (liam.heaphy@ichec.ie)

Submitted: 5 November 2025 **Published:** 26 November 2025

Issue: This editorial is part of the issue “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse” edited by Liam James Heaphy (University of Galway) and Philip Crowe (University College Dublin), fully open access at <https://doi.org/10.17645/up.i461>

Abstract

This thematic issue explores the role of heritage conservation in climate mitigation and adaptation by examining the convergences between retrofitting heritage buildings, the circular economy, urban revitalisation, sustainable communities, and sense of place. The diverse contributions focus on the place of heritage in circular economy policies, retrofitting, and climate adaptation. Collectively, the articles set out the contribution of heritage conservation as a resource for economic growth, employment, and social cohesion, and as a form of climate action by diverse actors at different scales in the low-carbon transition.

Keywords

adaptive reuse; circular economy; climate resilience; embodied carbon; heritage conservation; life cycle analysis

1. Introduction

The built environment has a huge impact on the biosphere, affecting multiple planetary boundaries (Kuittinen, 2023). For example, urban settlements contribute an estimated 70% of global CO₂e (carbon dioxide equivalent) emissions (IPCC, 2023) and the buildings and construction sector is responsible for an estimated 34% of global CO₂e emissions, reflecting insufficient progress in meeting Paris Agreement targets (UNEP, 2025).

There is an urgent need to decarbonise, as reflected in ambitious policy targets for the built environment such as the revised European Performance of Buildings Directive, which stipulates that “new buildings

should be zero-emission buildings by 2030, and existing buildings should be transformed into zero-emission buildings by 2050” (“Directive (EU) 2024/1275,” 2024, p. 4). However, many countries are experiencing continued urban expansion to meet housing needs, which can be in conflict with these carbon targets if sustainable solutions are not implemented (OECD, 2024). For example, in Ireland the current Programme for Government includes a plan to deliver more than 300,000 new homes between 2025 and 2030 (Rialtas na hÉireann, 2025). It is recognised that unless there is significant reuse of vacant buildings and accounting for whole life carbon in construction and retrofits, Ireland will not nearly meet carbon targets of a 51% reduction (on 2018 levels) by 2030 (O’Hegarty & Kinnane, 2022). The IPCC’s Sixth Assessment Report considers that established cities “will achieve the largest GHG emissions savings by replacing, repurposing, or retrofitting the building stock, targeted infilling and densifying, as well as through modal shift and the electrification of the urban energy system” (IPCC, 2023, p. 864), and there are calls in the literature for the avoidance of new construction, particularly in the Global North, and instead a focus on adaptive and sufficient use of existing buildings (Kuittinen, 2023).

Vacancy and underuse are persistent issues in many countries, for example throughout Europe (Turnbull, 2023), where an estimated 20% of the total stock of dwellings (including second homes) were recorded as vacant in national censuses (Eurostat, 2021; FEANTSA, 2025). Vacancy is associated with negative impacts on placemaking, sense of belonging, and community well-being (Armstrong et al., 2023). However, vacant sites and buildings can be framed as spaces for change and transformation (Pagano & Bowman, 2004) and to represent the spatial dimension of adaptive capacity in an urban area (Crowe & Foley, 2017). In older, established urban settlements in Europe and elsewhere, many of these buildings are recognised in conventions and legislation for their architectural quality and heritage value.

Increasingly, the commonality of purpose between heritage conservation and the circular economy has been recognised in relation to retaining heritage assets in use without losing what is understood as their integrity or character (Huuhka & Vestergaard, 2019; Wise et al., 2021), which helps define and differentiate places. Heritage conservation practice can promote a sense of belonging and a sense of place (Vafaie et al., 2023), and in recent years the emphasis has shifted from the heritage of an individual building to a systems approach that recognises the cultural and natural heritage of a place, as promoted in the recommendation on the historic urban landscape (UNESCO, 2011) and in the Burra Charter (ICOMOS, 2013).

Perhaps less accounted for is the contribution of heritage conservation to climate mitigation through adaptive reuse (Baker et al., 2021), principally because heritage buildings represent a store of embodied carbon, and their reuse requires significantly less environmental resources compared to the demolition and construction required for an equivalent new build (ICOMOS, 2019; O’Hegarty & Kinnane, 2022), particularly when siteworks (infrastructure, landscaping, and land use change) are taken into account. However, the process of renovating a building does contribute to embodied carbon emissions (Mastrucci et al., 2020), and in Europe, the requirement to assess embodied carbon emissions has recently been introduced in the revised Energy Performance in Buildings Directive (EPBD; “Directive (EU) 2024/1275,” 2024).

The adaptive reuse of heritage buildings also promotes a culture of stewardship through good maintenance (Historic England, 2019), and often involves the use of local, reclaimed, or recycled materials alongside traditional industries and skills (ICOMOS, 2019), in line with principles of the circular economy and key policy initiatives such as the European Green Deal (European Commission, 2021). It also fosters the efficient

use of urban centres through compact urban growth, reducing urban sprawl (Giraud-Labalte et al., 2015; ICOMOS, 2019) and facilitating more people to live in town centres, potentially leading to urban revitalisation, improved social cohesion, and sustainable communities (Crowe, 2019).

This thematic issue, “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse,” sets out to provide some insight into the role of heritage conservation in the urgent task of decarbonising the built environment. The five articles included broadly cover three areas: adaptive reuse, climate adaptation, and synergies between heritage conservation and the circular economy.

2. The Environmental Case for Adaptive Reuse

There is now a considerable accumulation of life cycle assessment studies of buildings (Ferreira et al., 2015; Marique & Rossi, 2018; O’Hegarty et al., 2020) which support the well-established titular finding that “the greenest building is the one that is never built” (Lucuik et al., 2010). However, this generally accepted finding is being mediated and shaped by larger discussions on how results are dependent upon methodological choices (Moncaster et al., 2018), upon the ability to reuse materials and components (Akhimien et al., 2021; Weiler et al., 2017), and enmeshed with the complexities of altering protected heritage structures (Baker et al., 2021).

In Europe, there have been successive policies on the circular economy as it relates to the built environment, including the European Taxonomy and the revised EPBD, previously mentioned. There is also considerable opportunity to build cohesive approaches to adaptive reuse that combine reduced greenhouse gas emissions from the built environment with architectural conservation. Donarelli (2025, this issue) explores the implications of the revised EPBD for heritage and circular economy policies in Sweden. The author notes how definitions of zero energy may work together with heritage values to create measured approaches to heritage buildings that move towards a more sustainable built environment.

Further complexities arise when consideration expands to newly developed policies to tackle urban vacancy and a recognition that adaptive reuse of underutilised urban units and buildings reduces our need to extract and manufacture materials for new buildings or wholesale replacements of buildings. Warda et al. (2025, this issue) discuss approaches to adaptive reuse in Germany, taking as examples the Denkmalverein Hamburg (Society for Architectural Heritage) and Denkmalverein Sachsen, which actively map existing heritage structures and their status as well as materials. They explore the potential for extended concepts of the circular economy, which seek to maintain and reuse existing built fabric in alignment with heritage values.

While partly in response to urban shrinkage, the German approach shows authorities can plan for future growth by actively banking both buildings and materials for future adaptive reuse. Such approaches broadly cohere with an increasing focus on neighbourhood-scale retrofit programmes (Hofman et al., 2021), particularly when looking to the embodied carbon savings that can be potentially made through such programmes. Scaled approaches to adaptive reuse at the neighbourhood and settlement scales (Crowe, 2019) can help build climate and social resilience alongside urban improvement, preservation of heritage, and modernisation.

3. Adapting Heritage Settlements

The climatic conditions to which vernacular settlements are attuned are changing due to anthropogenic greenhouse gas emissions, which shift the experience both at the regional scale and in the microclimates experienced in urban settlements (Oke et al., 2017). In this issue, Cherchi et al. (2025) consider thermal comfort in a traditional Sardinian village which has undergone various changes to its urban fabric over the centuries. They explore low-tech approaches to increase thermal comfort in small urban public spaces during high background temperatures, while respecting the historical fabric and morphology of the settlement.

The oil-rich nations of the Middle-East are undergoing large-scale changes as the world economy moves away from fossil fuel dependency. Iran, historically a major exporter of crude oil but now partly locked out of trade, also has a recent context of social and military conflict and large demographic growth. Gharaati et al. (2025, this issue) evaluate the prospects for the adaptive reuse of a former 1930s German-built iron foundry to the west of Tehran. Their study employs innovative future visioning and “imaginary future generations” methods through workshops to map out future possibilities for this large-scale industrial heritage site. Their two-part method of adaptive reuse possibilities and then future scenarios allows them to find paths that negotiate climate impacts, energy consumption, and societal change.

4. Synergies Between Heritage Conservation and the Circular Economy

Linking many of the articles in this thematic issue is the overlap of heritage conservation and circular economy principles and practice. Purposeful measures towards climate resilience and mitigation, protection of nature, and preservation of built and cultural heritage, all suggest a reverence for sense of place and the delicate foundations upon which this sense is built.

Vieveen et al. (2025, this issue) provide four empirical case studies of recently retrofitted listed heritage buildings in the Netherlands. For each, they cover the following both before and after the retrofit: architectural and heritage appraisal, energy consumption, and CO₂e emissions. They find that, on average, “energy performance improved with a CO₂ reduction of approximately 52%,” with the CO₂e results shaped heavily by changes in energy usage. They note that this efficiency gain does come at a cost of their measured heritage values, but that on the whole, the changes were modest and respectful of the buildings’ identity and history.

5. Conclusion

As discussed in this issue by Warda et al. (2025), Donarelli (2025), and Gharaati et al. (2025), our built heritage forms part of a shared resource that can further our goals for the circular economy and the climate challenge. Key future developments will be to integrate life cycle assessment considerations into combined energy performance and heritage value assessments. For instance, the development of building renovation passports in Europe (Buchholz & Lützkendorf, 2023) may provide international templates that might be adapted elsewhere for energy pathways for existing buildings to meet climate goals. Approaches to vacancy management in France, Scotland, and Germany (Warda et al., 2025) can also be developed further to quantitatively recognise the embodied carbon emissions that are saved through reuse of both existing

buildings (including heritage structures) and the urban services with which they are already integrated as compared to further greenfield and edge development.

Finally, we note that while we have looked at alignments between heritage conservation and climate policies through adaptive reuse, a further consideration will be that of the expanding policy space to halt and reverse biodiversity loss (Humphrey et al., 2025). Reusing and reinvigorating our urban places and buildings is also critically important for minimising human encroachment into our dwindling biodiversity reserves.

Acknowledgments

We extend our sincere gratitude to all the scholars and authors who have engaged with this thematic issue. We also thank the editorial team for their guidance, and the peer reviewers who so diligently reviewed contributions with many helpful comments. We also acknowledge the work of Ciara Reddy, Rola Abu Hilal, and the rest of the team on the EPA Ireland-funded TREBUChEt project.

Conflict of Interests

The authors declare no conflict of interests.

References

- Akhimien, N. G., Latif, E., & Hou, S. S. (2021). Application of circular economy principles in buildings: A systematic review. *Journal of Building Engineering*, 38, 102041. <https://doi.org/10.1016/j.jobbe.2020.102041>
- Armstrong, G., Wilkinson, S., & Cilliers, E. J. (2023). A framework for sustainable adaptive reuse: Understanding vacancy and underuse in existing urban buildings. *Frontiers in Sustainable Cities*, 5, 985656. <https://doi.org/10.3389/frsc.2023.985656>
- Baker, H., Moncaster, A., Remøy, H., & Wilkinson, S. (2021). Retention not demolition: How heritage thinking can inform carbon reduction. *Journal of Architectural Conservation*, 27(3), 176–194. <https://doi.org/10.1080/13556207.2021.1948239>
- Buchholz, M., & Lützkendorf, T. (2023). European building passports: Developments, challenges and future roles. *Buildings & Cities*, 4(1), 902–919. <https://doi.org/10.5334/bc.355>
- Cherchi, G., Santus, A., Fiorino, D. R., & Ferrari, S. (2025). Microclimate assessment and outdoor human comfort enhancement of a historic village in Sardinia, Italy. *Urban Planning*, 10, 10708. <https://doi.org/10.17645/up.10708>
- Crowe, P. R. (2019). *Incentives for the reuse of vacant buildings in town centres for housing and sustainable communities in Scotland, Denmark and France*. The Collaborative Working Group for Housing and Sustainable Living. <http://rebuildingireland.ie/wp-content/uploads/2019/03/Report-2.pdf>
- Crowe, P. R., & Foley, K. (2017). Exploring urban resilience in practice: A century of vacant sites mapping in Dublin, Edinburgh and Philadelphia. *Journal of Urban Design*, 22(2), 208–228. <https://doi.org/10.1080/13574809.2017.1298401>
- Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings. (2024). *Official Journal of the European Union*. <https://eur-lex.europa.eu/eli/dir/2024/1275/oj/eng>
- Donarelli, A. (2025). Zero-emission and zero demolition: Promoting conservation interests through the implementation of the Energy Performance of Buildings Directive. *Urban Planning*, 10, 10631. <https://doi.org/10.17645/up.10631>

- European Commission. (2021). *European Green Deal: Commission proposes to boost renovation and decarbonisation of buildings*. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6683
- Eurostat. (2021). *The 2021 population and housing censuses in the EU*. Publications Office of the European Union.
- FEANTSA. (2025). *Reclaiming vacant spaces to tackle housing and homelessness crises in Europe*. https://www.feantsa.org/public/user/Resources/2510092_FEANTSA_-_Report_Reclaiming_vacant_spaces_WEB_spreads.pdf
- Ferreira, J., Duarte Pinheiro, M., & de Brito, J. (2015). Economic and environmental savings of structural buildings refurbishment with demolition and reconstruction—A Portuguese benchmarking. *Journal of Building Engineering*, 3, 114–126. <https://doi.org/10.1016/j.jobe.2015.07.001>
- Gharaati, F., Mahdavinejad, M., Meyer, M., & Saijo, T. (2025). Sustainable futuristic energy scenarios for low-carbon industrial heritage: Green adaptive reuse of Karaj iron foundry. *Urban Planning*, 10, 10600. <https://doi.org/10.17645/up.10600>
- Giraud-Labalte, C., Pugh, K., Quaedvlieg-Mihailović, S., Sanetra-Szeliga, J., Smith, B., Vandesande, A., Boruń-Jagodźńska, K., & Thys, C. (2015). *Cultural heritage counts for Europe: Full report*. International Culture Centre.
- Historic England. (2019). *Heritage Counts 2019—There's no place like old homes: Re-use and recycle to reduce carbon*. <https://historicengland.org.uk/research/heritage-counts/2019-carbon-in-built-environment/carbon-in-built-historic-environment>
- Hofman, P., Wade, F., Webb, J., & Groenleer, M. (2021). Retrofitting at scale: Comparing transition experiments in Scotland and the Netherlands. *Buildings & Cities*, 2(1), 637–654. <https://doi.org/10.5334/bc.98>
- Humphrey, J. E., Selinske, M. J., Garrard, G. E., Zu Ermgassen, S. O. S. E., Addison, P. F. E., Kiss, B. M., Burgass, M., Chimbwandira, S. J., Connop, S., Duffus, N. E., Hartwell, R., Moberly, R. L., Nash, C., Nolan, P., Staples, J., & Bekessy, S. A. (2025). How do we achieve nature positive? A vision and targets for the UK residential and commercial development sector. *Npj Urban Sustainability*, 5(1), 14. <https://doi.org/10.1038/s42949-025-00204-0>
- Huuhka, S., & Vestergaard, I. (2019). Building conservation and the circular economy: A theoretical consideration. *Journal of Cultural Heritage Management and Sustainable Development*, 10(1), 29–40. <https://doi.org/10.1108/JCHMSD-06-2019-0081>
- ICOMOS. (2013). *The Burra Charter: The Australia ICOMOS charter for places of cultural significance 2013*.
- ICOMOS. (2019). *The future of our pasts: Engaging cultural heritage in climate action. Outline of climate change and cultural heritage*. https://openarchive.icomos.org/id/eprint/2459/1/CCHWG_final_print.pdf
- IPCC. (2023). *Climate change 2022—Mitigation of climate change* (1st ed.). Cambridge University Press. <https://doi.org/10.1017/9781009157926.010>
- Kuittinen, M. (2023). Building within planetary boundaries: Moving construction to stewardship. *Buildings and Cities*, 4(1), 565–574. <https://doi.org/10.5334/bc.351>
- Lucuik, M., Huffman, A., Trusty, W., & Prefasi, A. (2010). The greenest building is the one that is never built: A life-cycle assessment study of embodied effects for historic buildings. In American Society of Heating, Refrigerating and Air-Conditioning Engineers – ASHRAE (Ed.), *Buildings XI, Thermal Performance of the Exterior Envelopes of Whole Buildings XI 2010. Proceedings* (p. 9). ASHRAE.
- Marique, A.-F., & Rossi, B. (2018). Cradle-to-grave life-cycle assessment within the built environment: Comparison between the refurbishment and the complete reconstruction of an office building in Belgium. *Journal of Environmental Management*, 224, 396–405. <https://doi.org/10.1016/j.jenvman.2018.02.055>
- Mastrucci, A., Marvuglia, A., Benetto, E., & Leopold, U. (2020). A spatio-temporal life cycle assessment

- framework for building renovation scenarios at the urban scale. *Renewable and Sustainable Energy Reviews*, 126, 109834. <https://doi.org/10.1016/j.rser.2020.109834>
- Moncaster, A. M., Pomponi, F., Symons, K. E., & Guthrie, P. M. (2018). Why method matters: Temporal, spatial and physical variations in LCA and their impact on choice of structural system. *Energy and Buildings*, 173, 389–398. <https://doi.org/10.1016/j.enbuild.2018.05.039>
- O'Hegarty, R., Colclough, S., Kinnane, O., Lennon, D., & Rieux, E. (2020). Operational and embodied energy analysis of 8 single-occupant dwellings retrofit to nZEB. In Civil Engineering Research Association of Ireland (Ed.), *Civil Engineering Research in Ireland 2020: Conference Proceedings* (pp. 383–388). <https://sword.mtu.ie/cgi/viewcontent.cgi?article=1066&context=ceri>
- O'Hegarty, R., & Kinnane, O. (2022). Whole life carbon quantification of the built environment: Case study Ireland. *Building and Environment*, 226, 109730. <https://doi.org/10.1016/j.buildenv.2022.109730>
- OECD. (2024). *Global state of national urban policy 2024: Building resilience and promoting adequate, inclusive and sustainable housing*. <https://doi.org/10.1787/4db6994c-en>
- Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban climates*. Cambridge University Press. <https://doi.org/10.1017/9781139016476>
- Pagano, M., & Bowman, A. (2004). Vacant land as opportunity and challenge. In R. Greenstein, Y. Sungu-Eryilmaz, & Lincoln Institute of Land Policy (Eds.), *Recycling the city: The use and reuse of urban land* (pp. 15–32). Lincoln Institute of Land Policy.
- Rialtas na hÉireann. (2025). *Programme for Government 2025—Securing Ireland's future*. <https://gov.ie/en/departments-of-the-aoiseach/publications/programme-for-government-2025-securing-irelands-future>
- Turnbull, D. (2023). *Tools to deal with vacant housing*. Housing Europe. <https://www.housingeurope.eu/resource-1823/tools-to-deal-with-vacant-housing>
- UNEP. (2025). *Not just another brick in the wall: The solutions exist—Scaling them will build on progress and cut emissions fast*. *Global Status Report for Buildings and Construction 2024/2025*. <https://doi.org/10.59117/20.500.11822/47214>
- UNESCO. (2011). *Recommendation on the historic urban landscape*. <https://whc.unesco.org/en/hul>
- Vafaie, F., Remøy, H., & Gruis, V. (2023). Adaptive reuse of heritage buildings; a systematic literature review of success factors. *Habitat International*, 142, 102926. <https://doi.org/10.1016/j.habitatint.2023.102926>
- Vieveen, M., Banninga, A., Munuswamy, T., & van der Schoor, T. (2025). Sustainable heritage buildings: The impact on heritage values, energy performance, and CO₂ emissions. *Urban Planning*, 10, 10578. <https://doi.org/10.17645/up.10578>
- Warda, J., Schiller, G., & Knippschild, R. (2025). Heritage in a circular economy: Integrating conservation, resource management, and community engagement. *Urban Planning*, 10, 10750. <https://doi.org/10.17645/up.10750>
- Weiler, V., Harter, H., & Eicker, U. (2017). Life cycle assessment of buildings and city quarters comparing demolition and reconstruction with refurbishment. *Energy and Buildings*, 134, 319–328. <https://doi.org/10.1016/j.enbuild.2016.11.004>
- Wise, F., Moncaster, A., & Jones, D. (2021). Rethinking retrofit of residential heritage buildings. *Buildings and Cities*, 2(1), 495–517. <https://doi.org/10.5334/bc.94>

About the Authors



Liam James Heaphy (PhD) is a research fellow at the Irish Centre for High-End Computing in the University of Galway. Liam's research is on climate change adaptation and the built environment, smart cities, and environmental planning. He has also co-authored several policy reports for national government in Ireland.



Philip Crowe (PhD) is Director of Research in UCD's School of Architecture, Planning and Environmental Policy, and co-Director of the UCD Centre for Irish Towns. Philip works on a range of research projects relating to town revitalisation, vacancy and adaptive reuse, compact urban growth, and citizen participation in processes of change.

Heritage in a Circular Economy: Integrating Conservation, Resource Management, and Community Engagement

Johannes Warda ¹ , Georg Schiller ² , and Robert Knippschild ^{2,3} 

¹ Institute for Archaeology, Heritage Conservation Studies and Art History, University of Bamberg, Germany

² Leibniz Institute of Ecological Urban and Regional Development (IÖR), Germany

³ International Institute Zittau of Technische Universität Dresden, Germany

Correspondence: Johannes Warda (johannes.warda@uni-bamberg.de)

Submitted: 23 May 2025 **Accepted:** 29 September 2025 **Published:** 5 November 2025

Issue: This article is part of the issue “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse” edited by Liam James Heaphy (University of Galway) and Philip Crowe (University College Dublin), fully open access at <https://doi.org/10.17645/up.i461>

Abstract

The building industry is one of the most resource-intensive sectors globally, accounting for significant environmental impacts through material extraction, processing, and waste generation. In the quest to mitigate climate change and preserve natural resources, the integration of circular economy (CE) principles into various sectors, including heritage conservation (HC), has gained notable attention. The CE framework corresponds with the general intention of HC efforts to preserve buildings of high cultural value. However, the intersection of CE with HC strategies to prolong the use of buildings often remains underexplored. This article seeks to address this gap by discussing an integrated perspective of CE and HC approaches, building on an expanded definition of CE. By looking at diverse stakeholders and forms of organisation within the HC community, including heritage practitioners in citizen initiatives and local communities, we explore how their practice can be regarded as implementation of CE strategies. Discussing the results, the article advocates for a shift in perspective to consider the various actors involved in HC and their capacities to adopt and promote circular practices. Through this integrated approach, the article aims at contributing to a deeper understanding of the synergies between CE and HC.

Keywords

adaptive reuse; circular economy; community engagement; heritage conservation; heritage values; resource management

1. Introduction

The building industry is one of the most resource-intensive sectors globally, accounting for significant environmental impacts through material extraction, processing, and waste generation. In the quest to mitigate climate change and preserve natural resources, the integration of circular economy (CE) principles into various sectors, including heritage conservation (HC), has gained notable attention (Foster, 2020; Gravagnuolo et al., 2021; Huuhka & Vestergaard, 2020). CE aims to redefine traditional linear economic models by promoting the sustainable use of resources through regeneration, reuse, and recycling. By extending the lifespan of buildings through maintaining, repairing, refurbishing, revitalising, and reusing, the environmental footprint associated with new construction can be significantly reduced. This CE framework corresponds with the general intention of HC efforts to preserve buildings of high cultural value. However, the intersection of CE with HC strategies to prolong the use of buildings often remains underexplored. This article seeks to address this gap by discussing an integrated perspective of CE and HC approaches, drawing on an expanded definition of CE that encompasses the strategic prolongation of building life cycles and the transformation of existing spaces (section 2). This perspective aligns with the overall goals of CE, which emphasise minimising material inputs and maximising the utility of existing resources (section 3). Conventional approaches often overlook the importance of agency—how individuals and organisations interact in their care efforts for built heritage. In the sense of “open heritage” (Oevermann & Szemző, 2023), we understand heritage not only to mean the objects deemed worthy of protection, but also a broad network of different actors and the political and institutional mechanisms to which they are subject in their conservation efforts. This article looks at diverse stakeholders and forms of organisation within the HC community (section 4), including heritage practitioners in citizen initiatives and local communities, and explores how their practice can be regarded as implementation of CE strategies.

Methodologically, this study relies on a literature review of the discourse on CE and HC strategies, supported by case studies that exemplify the integration of CE and HC principles. The focus of the case studies will be on heritage networks and citizens’ associations and thus on the level of local and intermediate actors who are often overlooked. The case studies are all located in Germany. The country’s long-standing tradition of citizen-led action for HC has led to a vital landscape of initiatives in the field which operate next to heritage protection authorities. These initiatives appear to bring in more integrated perspectives on future issues of HC and thereby push the authorities to act. In the light of key findings in the field on the difficulties of applying CE strategies for HC, the results of this article advocate for a shift in perspective in order to gain a deeper understanding of the synergies between CE and HC. The concluding remarks suggest looking at the various actors involved in HC and their capacities to adopt and promote circular practices, and to strengthen their cross-sectional cooperation (section 5).

2. Material Flows in the Built Environment and Their Environmental Impact

2.1. *The Global Flow of Materials*

The construction industry is one of the most resource-intensive sectors worldwide, exerting enormous environmental impacts. It alone is responsible for 35–45% of global material flows and generates 30–40% of global waste (Hertwich et al., 2020; Mhatre et al., 2021). Projections indicate that these pressures will intensify: Deetman et al. (2020) expect the global demand for building materials to double within

the next three decades, driven by the continuous expansion of the global building stock. At present, the anthropogenic material stock embedded in existing building infrastructure already amounts to 318.7 gigatons worldwide (Deetman et al., 2020).

Importantly, the consumption of construction resources is highly uneven across regions. Contrary to widespread assumptions, the highest per capita consumption of building materials does not occur in the rapidly urbanizing countries of the Global South. Instead, it is concentrated in the wealthy societies of the Global North, which—despite their relatively modest growth in new building stock—contribute disproportionately to global material demand (Schiller & Roscher, 2023). While in 2022, the rate of new building in developing and emerging countries was nearly 1.8 times higher than in the Global North (International Energy Agency, 2023), the latter continued to sustain excessive material throughput within existing building stock. This paradox can be explained by lifestyle factors rather than growth dynamics. High material consumption in affluent societies is largely driven by the maintenance, renewal, and upgrading of already well-equipped building stocks.

2.2. Impact

The immediate climate impacts of building materials arise from grey emissions, caused by the energy used in the processing of materials and during transportation. Their share, measured against global GHG emissions as a whole, is constantly increasing. According to a study by the United Nations, the share of emissions from material production in global GHG emissions rose from 15% in 1995 to 23% in 2015 (Hertwich et al., 2020). Nearly half of that comes from construction. The increasing significance of embodied emissions becomes even more apparent when considering buildings with different energy performance standards. While emissions decrease with the optimization of the operational energy performance of buildings, the material-related embodied emissions, from the production of the building materials used, continue to increase. In energy retrofitted buildings, embodied emissions are at the level of operational emissions or even above (Mahler et al., 2019). The enormous flows of resources and the associated environmental impacts are partly a result of the fact that material flows in the built environment have predominantly been organised linearly (López Ruiz et al., 2020).

3. Promoting the Continued Use of Buildings: The CE Perspective

3.1. Concepts and Definitions

To reduce the use of resources, the European Union is taking active measures to transform the construction industry towards circular systems (European Commission, 2020). Based on comprehensive research on existing CE definitions, Kirchherr et al. (2017) identify key characteristics of this concept. They refer to the so-called “4R framework” (Reduce, Reuse, Recycle, Recover) and highlight its inherent system perspective, the consideration of different levels (object, region, national, global), as well as the significance of new business models and consumption patterns for the implementation of circular concepts. Meanwhile, the “R” approach has been further expanded to what is now the widely recognized “9R framework” (Potting et al., 2017). “9R” makes a clear distinction between different approaches, aiming at the avoidance of resource flows, the more efficient provision of resources, the more intelligent and sufficient use of products, and finally the fundamental questioning of their necessity. Subsequently, the longer use of products, their

production using resources that are already within the anthropogenic material stocks and their energetic utilisation are also considered. The “9R framework” is organised along a scale from strategies of highest (“R0”) to lowest grade of circularity (“R9”), the latter being a totally linearly organised economy (Potting et al., 2017, p. 15). Strategy R0 demands the refusal of any production activity.

3.1.1. Diversification of CE Strategies

Bocken et al. (2016) summarize these approaches into three overarching groups: the smart use and production of products (narrowing), the extension of the lifespans of products and their parts (slowing), and the beneficial use of materials at the end of the lifespan of products and their parts (closing). Later, a fourth strategy was added, “regenerate” (Konietzko et al., 2020, p. 2). The application of these terms to the construction sector can be outlined as follows:

The term “closing” specifically refers to the closing of material loops, particularly in the field of construction material recycling. It may also encompass approaches that facilitate recycling by considering the separability of building materials during the design stage of buildings. This strategy is oriented towards the “end of life” phase of buildings and components, that is, the management of materials released after demolition. “Slowing” encompasses a broader field which can be summarised under the concept of “preserving the existing stock.” This involves utilising entire buildings or components for a longer time, effectively slowing down the material flow. The distinction between “slowing” and “closing” is not always clear-cut. Potting et al. (2017) clearly associate “closing” in the context of “useful applications of materials” with the material level, while “slowing” pertains to the product level and its components. In contrast, Konietzko et al. (2020) include in their definition of “closing” not only the reuse of materials through recycling but also the reuse of components. The attribution one follows should primarily be justified on a content basis.

In the construction industry, questions concerning material cycles focus heavily on technical issues related to material qualities and requirements stipulated in standards and regulations. Conversely, the field of component reuse is notably more complex and comprehensive. In addition to technical inquiries, this includes legal issues regarding, e.g., warranties, design and planning considerations for integrating used components into new buildings, and so forth. Hence, component reuse is closer to the complex questions related to preservation of existing stock and is more accurately assigned to this overarching strategy. This addresses the usage phase, which must be extended by repairing, refurbishing, revitalising, or repurposing buildings and components. “Narrowing,” or the streamlining of materials, signifies “less”: buildings and components are constructed more efficiently with a reduced material input. However, the social components of “narrowing” also involve questioning consumption patterns in the context of sufficiency approaches (e.g., less living space per capita) as well as considering new uses for buildings (e.g., shared spaces). “Regenerating,” mentioned as a fourth strategy, is underscored by the notion of making clean. It addresses the issue of pollutants, the use of renewable energy, and regenerating natural ecosystems. Again, there are numerous references to construction. This spans the discussion on appropriate limit values and suitable proofs regarding the handling of pollutants, through various possibilities of using and harnessing renewable energies, to the reframing of buildings from consumers of ecological services to producers, e.g., as energy providers (plus energy houses) or as elements in nature-based systems managing heat islands (green facades, etc.).

The description of the sub-strategies of circular construction highlights their breadth, which can be compared to the sustainable construction concept that has been on social and political agendas since the 1990s. Significant differences lie in the stronger emphasis on necessary systemic changes rather than primarily focusing on efficiency improvements, and a distinctly greater emphasis on intent of action—particularly reinforced by the demanded business models.

3.1.2. Challenges in Classification of CE Strategies and Their Effects

How can the presented strategies be classified in terms of their effects? Given the complexity of the strategies, this is not straightforward. However, the following trend statements can be hypothetically formulated based on plausible considerations and conceptual references in the literature on the strategies: Potting et al. (2017) see the highest potential for minimising resource use and avoiding waste generally in “narrowing strategies,” followed by “slowing” and “closing.” For the construction sector, this must be scrutinised further: Technical innovations aimed at increasing efficiency theoretically possess a very high potential for resource conservation and emissions reduction. For instance, Zhang et al. (2024) calculate a resource conservation potential of around 65% achievable through the combination of innovative technologies concerning the construction material concrete. They do not, however, consider the necessary socio-institutional change required to anchor new technologies in society and to promote market penetration. Additionally, technical innovations are predominantly oriented towards the construction of new buildings. Sufficiency approaches also hold great potential, although these mostly rely on theoretical models. Hertwich et al. (2020) identify resource conservation and emissions reduction potentials that extend far beyond the technical potentials—such as through drastic reductions in living space requirements. Achieving broad societal acceptance for this requires a profound transformation of values. Circular management of the existing building stock has a direct effect on reducing resource consumption and avoiding grey emissions if new construction is avoided by using existing buildings for longer. In this case, the material input required for maintenance and revitalisation is hardly significant (Knippschild et al., 2025). “Closing” favours the use of secondary resources and conserves natural raw materials. It can also help to reduce grey emissions if process energies for recycling are low and transport is kept short (Gruhler & Schiller, 2023). Regenerative strategies are associated with the aforementioned strategies and may reinforce or mitigate them.

4. Prolonging the Life of Buildings: HC and Agency

4.1. The HC Framework—Buildings as a Resource

The designation of heritage objects is fundamentally based on values and processes of valuation (Avrami et al., 2019). HC theory from as far back as 1900 highlighted the dual character of monuments, recognizing them as both materially present entities and historical testimonies. This raises essential questions about the features conveyed by their materiality and the cultural values attributed to them. In recent years, Critical Heritage Studies have placed significant emphasis on the constructed nature of heritage, arguing that heritage is not merely a reflection of intrinsic values but is also shaped by contemporary societal contexts, “a production of the past in the present,” as Harrison (2012, p. 32) puts it.

Conversely, both classical modern and current HC theory retain a strong material-oriented perspective, heavily influenced by 19th-century preservationists such as John Ruskin and Alois Riegl. Their contributions

help explain why materiality continues to play a central role in the discourse surrounding heritage, despite the growing recognition of the importance of cultural narratives and constructions in understanding heritage objects. Ruskin, for instance, contends that the unique value of historic buildings arises from their materiality, which reflects the passage of time and experiences they have endured and reminds the observer of the people who built them (Ruskin, 1849/1903, p. 245). Riegl's theory of values presented in *Der moderne Denkmalkultus* (1903) proves to be a highly elaborative reflection on the intentions of art works and the becoming of monuments. According to Riegl, monuments bear the capacity to give insight into the cycle of life and death (Riegl, 1903, p. 24). He conceives this aspect as a universal category that can be experienced equally by all people.

It is important to highlight, in the thoughts of Ruskin and Riegl, that when addressing the issue of materiality and the heritage values it embodies, the concept of the original as a specific, unaltered state is not significant. Instead, both Ruskin and Riegl recognise the inevitability of change over time and value it highly, finding the greatest worth or quality of a monument precisely in this characteristic. In Riegl's theory of values, this refers to the memory values, particularly the age value, which he clearly distinguishes from contemporary values, such as the novelty value of experiencing an unaltered work of art (Riegl, 1903, pp. 40–41; see also Augustiniok et al., 2023, on Riegl's contemporary values and adaptive reuse). Ruskin's and Riegl's contributions to the concept of HC can be summarized as follows: The embodied historical value of heritage buildings does not rest primarily in their architectural forms and features, but rather in their materiality, which serves as a testament to the passage of time. Initially aimed at opposing the completion and restoration of Gothic cathedrals, this understanding gave rise to the preservationist principle of prioritizing conservation over restoration.

The material values attributed to a building intersect with the broader concept of resource value within the building stock (Hauser, 2001; Petzet & Hassler, 1996). This change of perspective was decisive for the rediscovery, and the eventual boom, of adaptive reuse as a conservation strategy (Wong, 2017). The Venice Charter of 1964 is frequently acknowledged as the first set of universal guidelines informing adaptive reuse (The Venice Charter, 1964/2012, p. 46; Wong, 2017, p. 10). Today, reuse as a key element of building conservation has become a broadly discussed architectural design and urban planning strategy (Lenz & Pendlebury, 2022). Under the motto of “as found,” the reuse of buildings is even referred to as an architectural style of its own (Braae & Riesto, 2011).

4.1.1. Keeping It in a Good State: The Interplay of Maintenance, Repair, and Reuse

To conserve rather than to reconstruct also implies that historic buildings should be maintained in the state in which they present themselves once they are attributed heritage value. “Take proper care of your monuments, and you will not need to restore them,” is the famous quotation from Ruskin (1849/1903, p. 244). Consequently, all efforts should be directed at maintaining and repairing them in a state-of-the-art craftsmanship manner. The conservationist concept of repair is exclusively dedicated to preserving existing structures and not to be mixed up with measures directed only at the restoration of the outer appearance (Mader, 1999, p. 151). In its modernist form, this ideal is also laid down in The Venice Charter (1964/2012).

In the context of modern architecture, where regular maintenance and building upkeep is not a major concern, practical examples of a preventive strategy can primarily be found in the HC sector. The “Monumentenwacht,” or Monument Watch initiatives, conceive of the maintenance of historic buildings as a common challenge that should be met with a communal organisation form. Originally founded in the

Netherlands in the 1970s, the idea spread to Flanders, Denmark, Portugal, and other European countries (Wu & van Laar, 2021). In Germany, the “Moumentenwacht” has gained some attention over the past decade. The Bavarian State Preservation recommended to introduce similar initiatives to implement an integrated structure for the “facility management” of historic monuments (Bayerisches Landesamt für Denkmalpflege, 2016, p. 35). The only similar initiative so far which is clearly inspired by the Dutch example is the “Monumentendienst” in the Rhine-Weser region (Monumentendienst, n.d.).

4.1.2. The Ideal of Craftsmanship and HC Education

HC theory and practice have long been based on the ideal of proper craftsmanship, which includes necessary maintenance work, repairing building components, and partially replacing them. In the aftermath of the European Architectural Heritage Year 1975, which aimed primarily at changing the demolition politics of urban renewal during that time, craftsmanship became a new focal topic of the heritage community at the European level. For example, a recommendation adopted by the Council of Europe (CoE) in 1986 aimed at “the promotion of craft trades involved in the conservation of the architectural heritage” (CoE, 1986). While the Council efforts focused on training, international exchange of skills, and contracting, the aspect of material integrity of heritage objects as well as the practice of using reclaimed materials were also acknowledged (CoE, 1986, p. 3). Currently, on the level of built heritage research and teaching, we observe a shift towards an integrative approach of heritage and architectural reuse practices in a broader sense. At RWTH Aachen University, a tenured assistant professorship will be established in 2025/26 with a specialisation in HC and building stock maintenance. Prospective candidates are expected to demonstrate practical experience in what could be called CE strategies both applied to listed and non-listed buildings, including the management of modern materials such as concrete and plastics. The new professorship will follow up on the current chair who has a more classical HC profile (Academics, 2025). Also, initiatives such as the study programme “Handwerk und Bauerhalt” (Crafts and Building Preservation) at Coburg University of Applied Sciences build on the attempts to strengthen the ties between HC, the craft trades, and architectural design (Hochschule Coburg, 2024).

4.2. Who Cares? Heritage Actors and Agency at the Intermediate Level and Bottom-Up

After discussing strategies in the previous section that are rooted in the classical HC approach, the following section will focus on examples where the preservation of buildings occurs under different conditions and in the context of the emergence of new institutional structures and groups of actors. The perspective taken here is informed, as mentioned above, by the open heritage concept. Oevermann and Szemző (2023, p. 159) define open heritage as a framework for addressing the various ways in which heritage is preserved, including the interplay between different local, institutional, and community constellations. Open heritage appears as a type of holistic planning tool that resolves the contradictions and obstacles that normally accompany HC projects by acknowledging them as normal parts of the process. The case studies presented below can be broadly divided into two distinct categories. The first category includes initiatives on the regional level that contribute to building awareness networks and critically engage with planning processes related to heritage sites, particularly when it comes to the demolition of buildings (4.2.1). The second category comprises actors and initiatives that view the building stock as a resource at the local level and actively manage it. This involves combating vacancy or salvaging building elements or materials in the spirit of urban mining when a building cannot be preserved in situ (4.2.2).

4.2.1. Heritage Networks and Citizens' Associations

Heritage networks and citizens' initiatives in the field of HC have played an ambivalent role in the past decades. Bottom-up initiatives can be credited with having put HC back on the agenda and helped to re-position it as a community-oriented framework during the waves of urban renewal in the 1960s and 70s. More recently, initiatives to reconstruct from scratch buildings destroyed in World War II or its aftermath, as in Dresden and Potsdam, have gained increasing attention. Concurrently, heritage activism aimed at strengthening efforts to prevent demolition, preserve the existing building stock, and put it back in use can also be observed. The first example discussed here is the Denkmalnetz Bayern, or Bavarian Heritage Network (DNB). As an umbrella organisation, it represents more than 220 initiatives and associations at the local and regional level and about 450 individuals. Since its foundation in 2012, the DNB has developed into a strong advocacy organisation for the preservation of monuments. In 2021, it was granted the status of an association with legal standing in Bavaria. This entitles the DNB to appeal planning laws affecting the built heritage as an official advocacy institution, comparable to environmental protection organisations. The focal point of its educational and public relations work is the website with its highlighted section titled "historic monuments & buildings" (DNB, n.d.). Designed as a kind of citizen science mapping, this section now features around 330 buildings classified into the four categories of "noteworthy," "endangered," "lost" (Figure 1), and "saved." The data not only highlights impending heritage losses but also brings together materials such as concepts presenting alternatives to demolition, statements, and media reports. In this way, an object- and case-based panopticon of heritage-informed and resource-sensitive urban planning is created. The DNB also facilitates community efforts to nominate buildings for the Bavarian list of historic monuments.



Figure 1. Remains of the demolition of the Kulmbach freight depot, a listed building (2023). The case was closely monitored by DNB and is now filed under the category "lost" in the database. Source: Courtesy of Dietmar Popp/Hans-Joachim Zeitler.

A similar database is provided by the Denkmalverein Hamburg, or Hamburg Society for Architectural Heritage. The Denkmalverein, focusing on the city state of Hamburg, describes itself as the “most important independent voice for monument protection in Hamburg” (Denkmalverein Hamburg, n.d.-a). The website features all types of buildings and civil engineering structures under the categories “endangered,” “saved,” and “lost” (Figure 2). The entries range from the small farmer’s cottage in the Hamburg suburbs to brutalist office and department stores’ buildings and even the Köhlbrand Elbe bridge. As with the DNB, the entries here also provide background information on the history of the buildings, numerous photos, and a press review. In many cases, it is only through the Denkmalverein’s research work that a building is deemed worthy of preservation and recognised by the monument authority. For example, a vocational school building by the renowned architecture office von Gerkan, Marg & Partner from 1990 was listed through an intervention by the Denkmalverein and nevertheless demolished in 2020 (Denkmalverein Hamburg, n.d.-b).

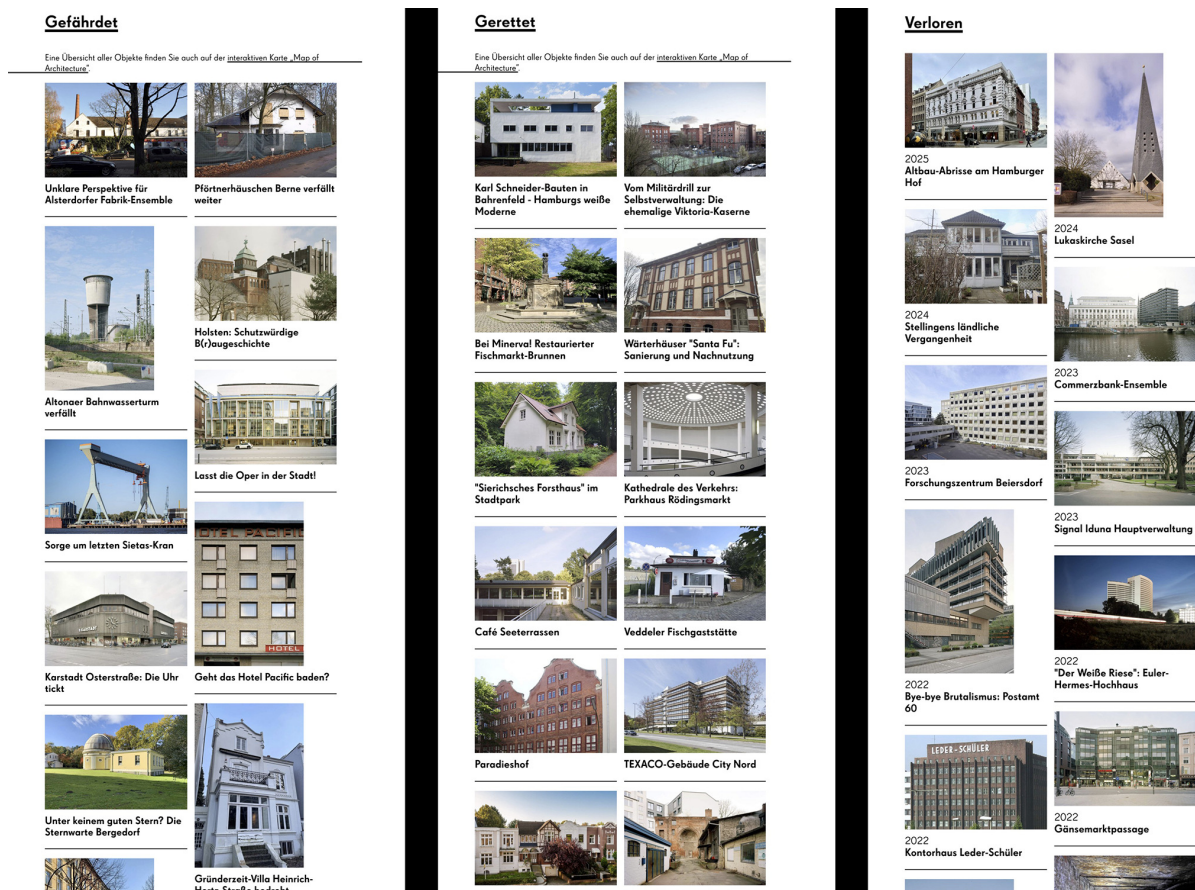


Figure 2. Database of buildings by Denkmalverein Hamburg (website screenshots, 2025). Source: Own.

4.2.2. Managing Vacancy and Building Components

In recent decades, many regions in Europe have been affected by the phenomenon of shrinkage due to demographic and economic changes. The resulting vacancy of historical buildings poses a significant challenge for municipalities, not only in the preservation of monuments but also in urban development (Knippschild et al., 2025; Veldpaus et al., 2019). Vacancies and vacant lots affect the cityscape and the subjective quality of life. It is not uncommon for demolitions to occur, encompassing both post-war housing estates and inner-city historic buildings, as seen in cities like Leipzig and Chemnitz (Nelle et al., 2017).

To counter the fatal logic of shrinkage and demolition with a perspective of preservation, representatives from HC and urban planning have called for a paradigm shift from “shrinking cities” to “waiting cities” (Sulzer, 2007, p. 23). The focus here is on the approach of understanding temporarily vacant buildings not as candidates for demolition, but as quiet resources for future revitalising urban development. These buildings should be actively preserved and structurally secured through appropriate measures.

Another instrument for the maintenance and activation of existing structures that has primarily developed over the past decade is known as vacancy management (Reichenbach-Behnisch et al., 2012). In this context, municipalities, particularly smaller and medium-sized towns, seek to establish a database on the available building stock to convey this information to potential users. Again, the aim is to interpret the vacancy of buildings not as an endpoint, but as a starting point for possible future development and to keep essential resources in reserve for this purpose. Evidence that vacancy management is not only effective in urban areas can be seen in examples from rural Franconia. Here, a state programme to promote inner urban development created incentives to actively manage building vacancies and infill development, thereby conserving resources and reducing land consumption (Bayerische Verwaltung für Ländliche Entwicklung, 2023). This has led to the emergence of a number of so-called municipal alliances, which actively integrate the tools of vacancy management and infill development into their local development strategies for a collective partnership of several municipalities. Founded in the early 2010s in particular, online research shows that many of the alliances are still active and continue to provide funding opportunities for individual and community-based development of vacant buildings (e.g., Hausnummer frei, n.d.; Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld, n.d.-a; Rhönallianz, n.d.). The alliances, such as the Rhön-Grabfeld region, have set up a real estate marketplace on their web platform and present good practice examples for the restoration of historically valuable buildings. In Rhön-Grabfeld, these are primarily impressive examples of revitalised historic timber-framed buildings (Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld, n.d.-b). Nevertheless, there is a considerable proportion of building plots for new construction projects in newly designated development areas on the web-based marketplaces—a practice that actually contradicts the aims of inner development (Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld, n.d.-c).

Since 2022, the Denkmalnetz Sachsen (DNS) has been addressing the issue of vacant monuments, particularly in smaller towns and rural areas in Saxony, with the aim of bringing these monuments back into use. The focus of its work is on networking initiatives, supporting individual owners and heritage activists, and, in particular, offerings for widely accessible vocational training in the crafts. DNS sees its work as a contribution to the construction transition (“Bauwende”). In 2024, it launched the project “Bauteilbörse,” which aims to create a platform for circular building in the field of monument preservation and to reconnect with the now-disappeared structures of component recovery and distribution (Wilson & Ditze, 2024). The DNS initiative aims to establish a framework for the procurement of already salvaged components. However, it is also important to consider how the salvage of components and materials can be carried out where they are generated—on the construction site and the building itself. Despite the many trades that have already specialised (again) in the technique of selective dismantling, in the view of many stakeholders, there are still numerous obstacles to the reuse of salvaged building components (Rudolph-Cleff, 2023, p. 147). The case of the Upper Palatinate city of Amberg illustrates which stakeholders and structural conditions can promote component management. This small urban community holds a significant ensemble of historic buildings with a characteristic roofscape (Stadt Amberg, 2014, p. 20). The proportion of roof

coverings made with historical, handmade tiles from the period between the 15th and 19th centuries is now only about 8.9% (Scher, 2023, p. 36). To maintain this overall impression, and increasingly for reasons of resource economy and sustainability efforts, the local heritage protection authority regularly mandates the preservation of roof coverings during construction work. This means that the tiles must be salvaged, examined, and stored until they can be reused (Figure 3). The city of Amberg works closely with property owners and the State Office for the Preservation of Monuments, and utilises a local network of experts, including a tile specialist. In some projects, the city administration also supported the logistics of transporting and storing the salvaged tiles for its own buildings or arranging for their use on other construction sites (Scher, 2023, pp. 39–40). However, due to technical reasons, such as the conversion of historical attics or high leakage requirements when insulating the roof, the reuse of roof tiles is often not feasible (Scher, 2023, p. 54).



Figure 3. Salvaged tiles stacked on the roof of Georgenstraße 53b, Amberg, ready to be transported into storage (2023). Source: Courtesy of Jana Scher.

5. Discussion and Conclusion

As introduced above, a central focus of the extended CE approaches, which are purported to have the strongest impact on local climate protection, is the preservation of material resources within the existing building stock. Strategies which promote this are, e.g., maintenance and an extended use of current buildings. Unlike the strategies of material-efficient new construction or the expansion of the recycling industry—both of which involve significant material transformations, energy-intensive processes, and consequently material-induced GHG emissions—maintaining the existing building stock has direct effects on resource conservation and GHG emission reduction.

It can be stated that modern HC strategies are closely linked to circular regimes of used building component management (Arlotta, 2019). However, the notion of HC and its principles as a strategy to generally prolong the life of buildings is still not the main focus of climate-related preservation research and political measures.

As a review by Foster and Saleh (2021) has shown, strategies for the adaptive reuse of cultural heritage buildings are hardly to be found in local efforts to build up CE structures. Instead, approaches and recommendations that aim to improve the energy performance of buildings as a contribution to climate protection still dominate (Burbat et al., 2024; Haas et al., 2021). Some in the HC community warn of the risks of a direct entanglement of both concepts, pointing out the importance of maintaining the cultural values of heritage objects. Roblee and Minner (2022, p. 52), for example, fear the loss of a sense of place and predict an even greater level of ecological costs. They compare the impact of CE on the built environment to the devastation of post-mining landscapes. With regard to the general concept, some researchers argue that CE approaches might overshoot the mark, due to their high theoretical differentiation and high number of participants (Weber & Jaeger-Erben, 2023, pp. 187–188). Huuhka and Vestergaard (2020, p. 6) suggest that the reluctance in HC towards the CE approach originates in the discipline's historic struggle for concepts such as authenticity and material integrity.

But is this the only reason? Our inquiry into the interplay of the HC and CE approaches leads us to conclude that there is a misperception of the different levels of consideration on which CE strategies are based and might be seen as relevant for HC. On the one hand, CE strategies are concerned with the entire building stock, claiming that every adaptive reuse project is a win. On the other hand, at the level of the individual building, CE strategies deal with building components, either for new construction or reuse. The reluctance to impose a strict CE policy on heritage buildings comes from the latter. To solve these issues, it might be helpful to change perspectives: CE and HC should not be viewed as two different and sometimes conflicting strategies next to each other. Rather, the focus should be on the similarities of both concepts at all scales and on overlapping strategies on the practical level. To address and actively resolve possible conflicts, it might be helpful to stick to the fundamental position of HC that the right strategy for transformation projects must always be determined on an individual object level. In this way, cultural values and the significance for the local and social context, among other aspects, can also be integrated into the project. Our case studies, focusing on various stakeholders, particularly at the mid and micro-levels and from bottom-up initiatives, have shown that there are ample opportunities to work towards the implementation of CE strategies. This does not mean that there is always a clearly defined framework for this. Rather, individual measures contribute to the CE strategies, especially in the sense of “closing” and “narrowing.” To practically implement CE strategies in this manner, we suggest focusing on three areas of action:

1. *Networking of key stakeholders and actors:* Regardless of the need to adjust legal frameworks, enhanced networking and collaboration among various state and civil society actors holds significant potential. This pertains to the revision and monitoring of the inventory, the pooling of personnel and material resources for conservation, and the extensive field of vocational training. While this approach is shared and widespread in most of the heritage community, it is socially under-supported in general and suffers from the disappearance of locally established circular structures that once existed (Warda et al., 2024). Especially in the case of the new municipal alliances formed to implement vacancy management and to coordinate infill development, stronger ties with HC actors could increase the effectiveness of the approach. As HC is supposedly associated with a limited economic or industrial dynamism, it is important for all stakeholders to point out the shift in value creation from industrially driven processes towards artisanal structures on the local level.
2. *Build on resource value:* The greatest potential in the integration of HC and CE concepts lies in the recognition of a material resource value. HC with a focus on material values can provide a

well-established set of strategies to prolong the life of buildings. For example, preserving the existing building stock, applying minimal interventions for maintenance, repair, and reuse, and using materials from within existing circles (this may include salvaged building components or materials from heritage buildings which could not have been maintained in place). Also, focusing on the longevity of buildings avoids lengthy construction sites and thus has a direct effect on the urban fabric and quality of life. The mapping of the building stock by bottom-up initiatives, as we have shown, might bring in a fresh take on the resource issue. It illustrates the fate of the building stock and can help to raise awareness, almost in the manner of an architecture guide, of how fast the built environment changes and what mass of high-quality built space is being demolished every day. In turn, the databases bear eloquent witness to the potential of the CE approach, but at the same time point to the continuing lack of effective ways of protecting existing building stock resources in order to revitalise them. The databases that are created from an HC perspective could complement the approach of the so-called material cadastres which aim to collect building material indicators for the building stock in order to calculate their global warming potential (Schinke et al., 2025).

3. Finally, a regional policy and spatial planning perspective is required: These include approaches to increase the attractiveness of cities and regions for newcomers, such as improved interregional accessibility, a stable educational and cultural infrastructure, and an open and tolerant urban society (Zöllter et al., 2024). If the dynamics of economic and demographic development, purchasing power, and demand for residential space to be converted are lacking, the above considerations will be difficult to apply in practice. At the moment, rental income in shrinking or shrunken regions, and in municipalities with significant vacancies, often does not cover the costs of refurbishments that are in line with the protection of listed buildings and, e.g., energy efficiency. This is why funding is needed for the integrated consideration of CE and HC for local authorities, owners, and other stakeholders in order to close the gap between the necessary investments and the revenue to be generated. In addition to the financial strain, the complexity of revitalising vacant, historical, and listed buildings is often an obstacle to their reuse (Ghoz, 2025). This requires approaches to providing information and reducing complexity, such as tools for standardisation or consulting services for professionalisation.

While the findings of the article predominantly pertain to the German landscape of HC actors, it remains uncertain how they might manifest on a European scale. This warrants further investigation in subsequent project-based research.

Conflict of Interests

The authors have previously published research articles in collaboration with employees of the Denkmalnetz Sachsen (DNS), a case study discussed above.

LLMs Disclosure

LLM tool HAWKI (an inter-university application programming interface to OpenAI; complies with academic data protection regulation and does not use data for LLM training) was used to improve grammar and style.

References

- Academics. (2025). *W1-Juniorprofessur (Tenure Track W2) Denkmal–und Bestandspflege*. <https://www.academics.de/jobs/w1-juniorprofessur-tenure-track-w2-denkmal-und-bestandspflege-rwth-aachen-university-aachen-1098664>

- Arlotta, A. I. (2019). Locating heritage value in building material reuse. *Journal of Cultural Heritage Management and Sustainable Development*, 10(1), 6–15. <https://doi.org/10.1108/JCHMSD-06-2019-0076>
- Augustiniok, N., Plevoets, B., Houbart, C., & van Cleempoel, K. (2023). Making built heritage: Riegl's present values in adaptive reuse. *Studies in History and Theory of Architecture*, 11, 139–156. https://sita.uauim.ro/article/11_08_Augustiniok_Plevoets_Houbart_Cleempoel
- Avrami, E., Macdonald, S., Mason, R., & Myers, D. (Eds.). (2019). *Values in heritage management: Emerging approaches and research directions*. The Getty Conservation Institute. <http://www.getty.edu/publications/heritagemanagement>
- Bayerische Verwaltung für Ländliche Entwicklung. (2023). *Ländliche Entwicklung in Bayern. Leistungsspektrum. Innenentwicklung in der Dorferneuerung, Initiative „Innen statt Außen“* [Brochure]. Bereich Zentrale Aufgaben. https://www.stmelf.bayern.de/mam/cms01/landentwicklung/dokumentationen/dateien/le_innenstatt_aussen_broschure-barrierefrei.pdf
- Bayerisches Landesamt für Denkmalpflege. (2016). *Denkmalpflege Themen 6*. https://www.blfd.bayern.de/mam/information_und_service/publikationen/denkmalpflege-themen_denkmalpflege-denkmalschutz2020_2016.pdf
- Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), 308–320. <https://doi.org/10.1080/21681015.2016.1172124>
- Braae, E., & Riesto, S. (2011). As found: A new design paradigm. *Nordic Journal of Architecture*, 1, 8–9.
- Burbat, D., Mahler, M., Seithel, S., & Eßig, N. (2024). *Klimaschutz bei denkmalgeschützten Gebäuden: Handlungsbedarf und Handlungsansätze: Abschlussbericht* (Climate Change, 13). Umweltbundesamt. <https://www.umweltbundesamt.de/publikationen/klimaschutz-bei-denkmalgeschuetzten-gebaeuden>
- Council of Europe. (1986). *Recommendation on the promotion of craft trades involved in the conservation of the architectural heritage* (No. R86/15). <https://search.coe.int/cm?i=09000016804d95db>
- Deetman, S., Marinova, S., van der Voet, E., van Vuuren, D. P., Edelenbosch, O., & Heijungs, R. (2020). Modelling global material stocks and flows for residential and service sector buildings towards 2050. *Journal of Cleaner Production*, 245, Article 118658. <https://doi.org/10.1016/j.jclepro.2019.118658>
- Denkmalnetz Bayern. (n.d.). *denkmäler & bauwerke*. <https://www.denkmalnetzbayern.de/erhaltenswerte-denkmaeler-bauten-gaerten>
- Denkmalverein Hamburg. (n.d.-a). *Home*. <https://www.denkmalverein.de>
- Denkmalverein Hamburg. (n.d.-b). *HEW-Schulungszentrum*. <https://www.denkmalverein.de/verluste/hew-schulungszentrum/.D>
- European Commission. (2020). *Circular economy action plan: For a cleaner and more competitive Europe*. <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0098>
- Foster, G. (2020). Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts. *Resources, Conservation and Recycling*, 152, 1–14. <https://doi.org/10.1016/j.resconrec.2019.104507>
- Foster, G., & Saleh, R. (2021). The adaptive reuse of cultural heritage in European circular city plans: A systematic review. *Sustainability*, 13(5), 1–15. <https://doi.org/10.3390/su13052889>
- Ghoz, L. (2025). A multidisciplinary categorization of challenges of reuse of residential Buildings. *Frontiers in Sustainable Cities*, 7. <https://doi.org/10.3389/frsc.2025.1576288>
- Gravagnuolo, A., Angrisano, M., & Nativo, M. (2021). Evaluation of environmental impacts of historic buildings conservation through Life Cycle Assessment in a circular economy perspective. *AESTIMUM*, 2021, 241–272. <https://doi.org/10.13128/aestim-10004>

- Gruhler, K., & Schiller, G. (2023). Grey energy impact of building material recycling—A new assessment method based on process chains. *Resources, Conservation & Recycling Advances*, 18, 200139. <https://doi.org/10.1016/j.rcradv.2023.200139>
- Haas, F., Exner, D., Herrera-Avellanosa, D., Hüttler, W., & Troi, A. (2021, April 14–16). *Making deep renovation of historic buildings happen—Learnings from the Historic Buildings Energy Retrofit Atlas* [Paper presentation]. SBE21 Sustainable Built Heritage, Bozen, Italy. <https://sbe21heritage.eurac.edu/paper-585117>
- Harrison, R. (2012). *Heritage: Critical approaches*. Routledge.
- Hauser, S. (2001). *Metamorphosen des Abfalls. Konzepte für alte Industrieareale*. Campus.
- Hausnummer frei. (n.d.). *Startseite*. <https://www.hausnummer-frei.de/startseite>
- Hertwich, E. G., Lifset, R., Pauliuk, S., Heeren, N., Ali, S., Tu, Q., Ardente, F., Berrill, P., Fishman, T., Kanaoka, K., Kulczycka, J., Makov, T., Masanet, E., & Wolfram, P. (2020). *Resource efficiency and climate change: Material efficiency strategies for a low-carbon future*. UN Environment Programme. <https://doi.org/10.5281/zenodo.14194614>
- Hochschule Coburg. (2024). *Fünf Millionen Euro für klimagerechtes Sanieren*. <https://www.hs-coburg.de/news/fuenf-millionen-euro-fuer-klimagerechtes-sanieren>
- Huuhka, S., & Vestergaard, I. (2020). Building conservation and the circular economy: A theoretical consideration. *Journal of Cultural Heritage Management and Sustainable Development*, 10(1), 29–40. <https://doi.org/10.1108/JCHMSD-06-2019-0081>
- Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld. (n.d.-a). *Herzlich Willkommen auf dem Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld*. <https://www.rhoen-grabfeld-innenleben.de>
- Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld. (n.d.-b). *Gute Beispiele für gelungene Sanierungen*. <http://www.rhoen-grabfeld-innenleben.de/gute-beispiele-fuer-gelungene-sanierungen>
- Innenentwicklungs-Immobilienportal des Landkreises Rhön-Grabfeld. (n.d.-c). *Immobilien*. <http://www.rhoen-grabfeld-innenleben.de/immobilien>
- International Energy Agency. (2023). *Global floor area and buildings energy intensity in the Net Zero Scenario, 2010–2030*. <https://www.iea.org/data-and-statistics/charts/global-floor-area-and-buildings-energy-intensity-in-the-net-zero-scenario-2010-2030>
- International Energy Agency. (2023). *Global floor area and buildings energy intensity in the Net Zero Scenario, 2010–2030*. <https://www.iea.org/data-and-statistics/charts/global-floor-area-and-buildings-energy-intensity-in-the-net-zero-scenario-2010-2030>
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221–232. <https://doi.org/10.1016/j.resconrec.2017.09.005>
- Knippschild, R., Rößler, S., Bräunel, M., Erhardt, D., Griesbach, J., Gruhler, K., Jehling, M., Schiller, G., & Zöllter, C. (2025). What (and how) revitalisation of cities and neighbourhoods can contribute to urban sustainability. *disP—The Planning Review*, 61(2), 4–18. <https://doi.org/10.1080/02513625.2025.2561509>
- Konietzko, J., Bocken, N., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, 253, 119942. <https://doi.org/10.1016/j.jclepro.2019.119942>
- Lenz, F., & Pendlebury, J. (2022). Adaptive reuse: A critical review. *The Journal of Architecture*, 27(2/3), 441–462. <https://doi.org/10.1080/13602365.2022.2105381>
- López Ruiz, L. A., Roca Ramón, X., & Gassó Domingo, S. (2020). The circular economy in the construction and demolition waste sector: A review and an integrative model approach. *Journal of Cleaner Production*, 248, 119238. <https://doi.org/10.1016/j.jclepro.2019.119238>

- Mader, G. T. (1999). Entstehung und Konzept des Bayerischen Bauarchivs Thierhaupten. In G. Klotz-Warischloher & M. Saar (Eds.), *Reparatur in der Baudenkmalpflege: Das Bayerische Bauarchiv Thierhaupten* (Hefte des Bayerischen Landesamtes für Denkmalpflege 101, pp. 148–159). Lipp.
- Mahler, B., Idler, S., Nusser, T., & Gantner, J. (2019). *Energieaufwand für Gebäudekonzepte im gesamten Lebenszyklus: Entwurf Endbericht*. Umweltbundesamt. <https://www.bmuv.de/forschungsbericht/bedeutung-des-energieaufwands-fuer-verschiedene-gebaeudekonzepte-im-gesamten-lebenszyklus-fuer-den-klimaschutz>
- Mhatre, P., Panchal, R., Singh, A., & Bibyan, S. (2021). A systematic literature overview on the circular economy initiatives in the European Union. *Sustainable Production and Consumption*, 26, 187–202. <https://doi.org/10.1016/j.spc.2020.09.008>
- Monumentendienst. (n.d.). *Wirkungsgebiet*. <https://www.monumentendienst.de/ueber-uns/wirkungsgebiet>
- Nelle, A., Großmann, K., Haase, D., Kabisch, S., Rink, D., & Wolff, M. (2017). Urban shrinkage in Germany: An entangled web of conditions, debates and policies. *Cities*, 69, 116–123. <https://doi.org/10.1016/j.cities.2017.02.006>
- Oevermann, H., & Szemző, H. (2023). What is open heritage? In H. Oevermann, L. Polyák, H. Szemző, & H. A. Miege (Eds.), *Open heritage: Community driven adaptive reuse in Europe: Best practice* (pp. 158–169). Birkhäuser.
- Petzelt, M., & Hassler, U. (Eds.). (1996). *Das Denkmal als Altlast? Auf dem Weg in die Reparaturgesellschaft*. Lipp.
- Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: Measuring innovation in the product chain*. PBL—Netherlands Environmental Assessment Agency. <https://www.pbl.nl/en/publications/circular-economy-measuring-innovation-in-product-chains>
- Reichenbach-Behnisch, J., Fläming, A., Kasek, J., Kröckel, J., & Freund, E. (2012). *Aktivieren des Stadtzentrums von Kleinstädten durch die verknüpfte Anwendung erfolgreicher Modelle aus Großstädten und ländlichen Regionen wie innovatives Leerstandsmanagement, installieren multipler Häuser und Förderung alternativer Wohnformen für die Generation Plus*. Fraunhofer IRB Verlag.
- Rhönallianz. (n.d.). *Herzlich willkommen bei der Brückenauer Rhönallianz*. <https://www.brueckenauer-rhoenallianz.de>
- Riegl, A. (1903). *Der moderne Denkmalkultus. Sein Wesen und seine Entstehung*. Braumüller.
- Roblee, A., & Minner, J. S. (2022). Deconstruction of place, acceleration of waste. In F. Heisel & D. Hebel (Eds.), *Building better—less—different: Circular construction and circular economy: Fundamentals, case studies, strategies* (pp. 52–53). Birkhäuser. <https://doi.org/10.1515/9783035626353-009>
- Rudolph-Cleff, A. (Ed.). (2023). *Bauteilkreis Region Darmstadt-Dieburg: Baumaterialien wiederverwenden: Ein Handbuch für alle zum Entdecken und Nachschlagen*. Technische Universität Darmstadt.
- Ruskin, J. (1903). *The works of John Ruskin: The seven lamps of architecture* (Library edition, Vol. 3). Allen. (Original work published 1849)
- Scherm, J. (2023). *Dachziegelkataster im südwestlichen Bereich der Amberger Altstadt—Bestandsaufnahme—Dokumentation—Analyse* [Unpublished master's thesis]. University of Bamberg.
- Schiller, G., & Roscher, J. (2023). Impact of urbanization on construction material consumption: A global analysis. *Journal of Industrial Ecology*, 27(4), 1021–1036. <https://doi.org/10.1111/jiec.13392>
- Schinke, R., Hennersdorf, J., Gruhler, K., Griebach, U., & Schiller, G. (2025). *Material cadastre of buildings in Germany 2022 (matcad2022, adm2022)* [Data set]. IOER Research Data Centre. <https://doi.org/10.71830/V2STEU>
- Stadt Amberg. (2014). *Alles nur Fassade? Gestaltungsfibel der Stadt Amberg* [Brochure]. https://amberg.de/fileadmin/Baureferat/Gestaltungsfibel_der_Stadt_Amberg.pdf

- Sulzer, J. (2007). Werteverstärkung: Von shrinking cities zu waiting cities. In *Revitalisierender Städtebau – Werte* (pp. 23–33). TUDPress.
- The Venice Charter. (2012). In ICOMOS Deutschland, ICOMOS Luxemburg, ICOMOS Österreich, & ICOMOS Schweiz (Eds.), *International principles and guidelines of conservation* (pp. 46–50). ICOMOS Deutschland. (Original work published 1964)
- Veldpaus, L., Fava, F., & Brodowicz, D. (2019). *Mapping of current heritage re-use policies and regulations in Europe: Complex policy overview of adaptive heritage re-use* (OpenHeritage: Deliverable 1.2). European Commission. https://ec.europa.eu/futurium/en/system/files/ged/d_1.2_mapping_of_current_heritage_re-use_policies_and_regulations_in_europe.pdf
- Warda, J., Schiller, G., Ditze, B., & Knippschild, R. (2024). Who initiates the material transition? On the role of circular economy and heritage conservation approaches for the transformation of the construction industry. *TATuP – Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis*, 33(3), 28–34. <https://doi.org/10.14512/tatup.7135>
- Weber, H., & Jaeger-Erben, M. (2023). Circular Economy: Die Wende hin zu ‚geschlossenen Kreisläufen‘ als stete Fiktion. In H. Weber (Ed.), *Technikwenden: Historische Perspektiven auf soziotechnische Um- und Aufbrüche* (pp. 169–197). Nomos Verlagsgesellschaft. <https://doi.org/10.5771/9783748942351-169>
- Wilson, V., & Ditze, B. (2024). *Eine Börse für historische Bauteile: Ein wichtiger Schritt für den Denkmalschutz und die Bauwende in Sachsen*. Denkmalnetz Sachsen. <https://www.denkmalnetzsachsen.de/beitraege/bauteilboerse-gestartet>
- Wong, L. (2017). *Adaptive reuse. Extending the lives of buildings*. Birkhäuser.
- Wu, M., & van Laar, B. (2021). The Monumentenwacht model for preventive conservation of built heritage: A case study of Monumentenwacht Vlaanderen in Belgium. *Frontiers of Architectural Research*, 10(1), 92–107. <https://doi.org/10.1016/j.foar.2020.07.007>
- Zhang, N., Gruhler, K., & Schiller, G. (2024). Assessing the impact of technical innovation on circular economy in the built environment by using cMFA-based system dynamics approach. *Journal of Building Engineering*, 92, 109782. <https://doi.org/10.1016/j.jobbe.2024.109782>
- Zöllter, C., Rößler, S., & Knippschild, R. (2024). In-migration for transforming peripheral locations through a real-world experiment? Experiment insights on location decisions in the medium-sized city of Görlitz, Germany. *GAIA – Ecological Perspectives for Science and Society*, 33(3), 286–294. <https://doi.org/10.14512/gaia.33.3.4>

About the Authors



Johannes Warda is senior lecturer in Historic Preservation at the University of Bamberg. Before, he has held research and teaching positions in Weimar, Dresden, at Akademie der bildenden Künste Wien, and FH Erfurt. His research focuses on the history and theory of architecture and preservation, sustainability, and building materials and resources.



Georg Schiller is head of the Anthropogenic and Natural Resources research group at the Leibniz Institute of Ecological Urban and Regional Development (IOER). He received his doctorate from the Brandenburg University of Technology Cottbus-Senftenberg with a focus on urban development and infrastructure adaptation.



Robert Knippschild has been the head of the Interdisciplinary Centre for Transformative Urban Regeneration (IZS) at the Leibniz Institute of Ecological Urban and Regional Development (IOER) since 2016. He is a university professor at the International Institute (IHI Zittau) of Technische Universität Dresden.

Microclimate Assessment and Outdoor Human Comfort Enhancement of a Historic Village in Sardinia, Italy

Giulia Cherchi ¹ , Alessandro Santus ² , Donatella Rita Fiorino ² , and Simone Ferrari ² 

¹ Department of Science of Antiquities, Sapienza University of Rome, Italy

² Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Italy

Correspondence: Giulia Cherchi (giulia.cherchi@uniroma1.it)

Submitted: 10 May 2025 **Accepted:** 11 August 2025 **Published:** 5 November 2025

Issue: This article is part of the issue “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse” edited by Liam James Heaphy (University of Galway) and Philip Crowe (University College Dublin), fully open access at <https://doi.org/10.17645/up.i461>

Abstract

In Sardinia (Italy), more than 80% of municipalities have fewer than 5,000 inhabitants and are affected by progressive depopulation. The abandonment of traditional production systems has disrupted the synergy between the built environment and its geographic, topographic, and climatic context, accelerating the decline of these villages. Despite this, many of these settlements retain a recognisable historical urban fabric and traditional architectural features. Among them, the village of Osidda was selected as a case study. Although its urban structure remains intact, recent interventions, including the addition of new buildings, materials, and paving, have compromised its original character. These changes, combined with climate change, have increased outdoor thermal discomfort, contributing to depopulation. To address this, the research employs the urban microclimate design methodology, which integrates architectural and microclimatic analysis and design. A stratigraphic urban study and mapping of traditional buildings were conducted using QGIS, forming the basis for simulations with the ENVI-met software (first aim). A typical critical summer day was simulated, and outdoor thermal comfort was assessed using the Predicted Mean Vote index, with elderly females as the reference case (second aim). On this basis, mitigation strategies (sun sails and pergolas, with and without water sprays) were tested through dedicated simulations (third aim). Results highlight the significant role of solar radiation and confirm the effectiveness of shading interventions. The study proposes an integrated methodology to enhance outdoor thermal comfort and to support heritage conservation strategies, fostering sustainable urban reactivation and social cohesion in historical villages.

Keywords

heritage conservation; outdoor thermal comfort; small historical villages; urban landscape

1. Introduction

Sardinia's territorial structure is historically characterised by a polycentric network of small villages, closely connected to their rural surroundings. Since the mid-20th century, the decline of traditional production systems has triggered a widespread process of depopulation, with a progressive shift of inhabitants towards coastal areas and larger urban centres. Today, more than 80% of Sardinian municipalities have fewer than 5,000 residents, and many face critical demographic, economic, and environmental challenges (Puggioni & Bottazzi, 2013).

However, these historic settlements have often preserved their traditional urban fabric and architectural heritage, shaped by centuries of adaptation to local geographic, topographic, and climatic conditions. This inherited knowledge from the past offers valuable lessons for sustainable living in the face of today's energy and climate crises: Buildings and open spaces were once designed to provide comfort with minimal resources, relying solely on passive strategies and the intelligent use of local materials. However, the widespread use of industrial materials (e.g., concrete) has contributed to urban overheating (Olgyay, 2013), and the increase in building density has hindered natural ventilation (Oke, 1988). Moreover, the growing reliance on mechanical heating, ventilation, and air conditioning (HVAC) systems further intensifies these effects. The consequences of these changes are evident not only in the worsening of outdoor thermal comfort and living conditions but also in the progressive deterioration of landscape quality. This deterioration manifests in the erosion of traditional urban and architectural features, the loss of vernacular building practices, and the replacement of local materials with inappropriate contemporary ones. These transformations have progressively disrupted the delicate balance that once existed between the urban environment and the surrounding natural context and resources.

Moreover, climate projections reinforce the urgency of addressing these challenges. In a scenario where no mitigation interventions are adopted, average temperature projections for the region in the period 2071–2100, when compared to the period 1971–2000, show a marked seasonality, with temperature increases ranging from a minimum of 4 °C in the fall to a maximum of 7.5 °C in the summer (Bucchignani et al., 2016). The European Environment Agency (2012) highlights that Southern Europe is already experiencing more frequent hot days (maximum temperature > 35 °C) and tropical nights (minimum air temperature > 20 °C), and the trend is projected to intensify. Future scenarios indicate an increase in the number of combined tropical nights and hot days, along with a clear northward expansion of the affected areas (Fischer & Schär, 2010). Furthermore, both the intensity and duration of heatwaves are expected to increase (Barriopedro et al., 2011; Sterl et al., 2008).

Given this, improving thermal outdoor comfort becomes an essential strategy not only for public health but also for enhancing the attractiveness of historic villages. This article examines how enhancing environmental quality in key areas of social life can meet contemporary needs for thermal comfort, resilience, and sustainability.

To this end, the research adopts a recursive and multidisciplinary design process, the urban microclimate design (UMD) methodology (see Chiri et al., 2020). This is an integrated approach combining two complementary perspectives: the architectural one, aimed at analysing the characteristics of urban spaces and built heritage, identifying both cultural values and critical issues; and the microclimatic one, focused on

understanding local microclimate dynamics and the interaction between built form and outdoor comfort. In this study, these different perspectives are integrated not only in the analytical phase but also in the development and selection of mitigation strategies.

In the UMD methodology, various design and planning strategies are employed to optimise thermal comfort, air quality, and energy efficiency at both the building and the urban scales, contributing to the creation of comfortable, efficient, sustainable, and resilient environments. Excluding those strategies specifically aimed at enhancing pollutant dispersion and energy performance, and following the classification proposed by Lai et al. (2019), UMD mitigation strategies for improving outdoor thermal comfort can be grouped into four main categories:

- Geometrical strategies, which rely on the shape, layout, and orientation of buildings or shading structures;
- Greening strategies, which exploit the thermoregulatory and shading properties of vegetation;
- Evaporative cooling strategies, which use the cooling potential of water through evaporation;
- Surface strategies, which optimise the thermal and reflective properties of ground and building materials.

Geometrical strategies primarily act by modifying ventilation and the sky view factor (which represents the amount of sky visible from a given point). In the planning phase, strategies using the urban canyon aspect ratio (e.g., Oke, 1988), the building aspect ratio (e.g., Garau et al., 2019), the street orientation (e.g., Ng, 2010), the building shape (e.g., roof shape, Ferrari et al., 2017; or courtyard shape, Ferrari & Tendas, 2024), the building height change (e.g., Nardecchia et al., 2018), the balconies (e.g., Jon et al., 2023), among others, can be effective. However, they can rarely be employed in the historic built environment, where only strategies like shading (e.g., Cortiços et al., 2024), windbreak structures (e.g., Peng et al., 2022), or wind-catchers (e.g., Zhang et al., 2024) are feasible.

Greening strategies act both passively, by modifying ventilation and shading, and actively, by reducing the surrounding air temperature through transpiration (Oke, 2002). Green roofs or pavements (e.g., Cuce et al., 2025), green walls (e.g., Zuckerman et al., 2025), pergolas (e.g., Watanabe et al., 2014), or planting trees or edges, can be used both within planning phases and as an addition to existing settlements. Even if they have a measured positive effect on people's wellness perception (e.g., Qin et al., 2013), the increase in humidity and the maintenance costs must be taken into account.

Evaporative cooling strategies take advantage of the temperature drop due to the heat subtraction when water evaporates (Manteghi et al., 2015). Typical interventions can be the introduction of artificial water bodies (e.g., Xue et al., 2015) or sprays (Ulpiani, 2019). These strategies can be effective in dry climates, where increased humidity can have positive effects.

Surface strategies typically make use of high albedo materials (often referred to as cool materials) and surfaces to reflect the direct solar radiation and reduce the heat absorption (e.g., Kumar Donthu et al., 2024). Even if cool materials are effective on single buildings (e.g., Santamouris, 2014), many studies have highlighted that they cause a decrease in the outdoor comfort due to the reflected radiation (e.g., Taleghani & Berardi, 2018; Yang et al., 2016).

Lai et al. (2019) have highlighted that the geometrical strategies are the most effective in reducing outdoor human thermal stress, followed by the greening and evaporative cooling strategies, while the surface strategies tend to worsen outdoor thermal conditions. A combination of strategies can be more effective than the use of a single one (e.g., Zhao et al., 2024).

As stated by Woolley (2003), comfortable urban outdoor spaces can highly improve the vitality of public spaces, bringing various benefits to the people in both physiological and social terms. Consequently, one of the main focuses when dealing with urban outdoor spaces should be outdoor comfort. Following Nicol and Humphreys (2002), outdoor thermal comfort can be defined as “a psychological state that expresses satisfaction with the thermal environment through subjective evaluation.” However, summarising it in a single quantity is complicated, as both objective variables (such as wind speed, humidity, temperature, solar irradiation) and subjective ones (such as age, gender, activities, heat sensitivity, clothing) contribute to its definition (Yin et al., 2022). Coccolo et al. (2016) have highlighted this difficulty in their review of outdoor human comfort indices, classified into three main categories: the thermal indices, the empirical indices, and the indices based on linear equations. Among the thermal indices, the Predicted Mean Vote (PMV) is based on the energy balance of an individual. It is expressed as a vote representing the mean satisfaction (and the related thermal stress) sensed by a group of people, with zero being the vote for optimal comfort condition, positive values indicating thermal discomfort related to heat stress and negative values linked to cold stress. The PMV is standardised by ISO 7730 (International Organization for Standardization, 2005) and, unlike other indices, can be evaluated directly using measured or simulated quantities (Park et al., 2024). These quantities can be measured in situ using instruments at single points, but obtaining maps of them in the entire area of interest can be resource-consuming. For this reason, the use of software to simulate the urban microclimate is often essential.

The UMD methodology is typically applied to large, modern cities, while in the present study it is adapted and applied to the specific spatial, cultural, and regulatory constraints of small historical settlements, addressing a recognised gap in the urban thermal outdoor microclimate research field (Battisti, 2017; Cirasa, 2011; Spanedda, 2007).

Osidda, a small historical rural village in northern Sardinia (Italy), was selected as the case study (Figure 1). The village stands on the western margin of the Bitti-Buddusò granite plateau, in a broadly flat landscape, amidst oak forests and bordered by the rivers Tirso and Molò. Its territory has been inhabited since prehistory, with significant archaeological remains (Di Cecilia, 1999). The original medieval settlement of Osidda (Zirottu, 2005), characterised by grey granite low-rise houses with limited use of courtyard spaces, gradually developed along the main streets over time. In the 19th century, the existing built heritage was enriched by the new architectural typology of the palazzo, incorporating a unique decorative terrace, the *altana* (Bianco & Cuboni, 2009; Fiorino & Grillo, 2023). More recently, concrete structures and modern buildings have been added to the historical layers. Although Osidda experienced a process of depopulation since the mid-20th century, from 1900 to 1960 it maintained a stable population of between 500 and 600 inhabitants, when it functioned as a significant urban centre. By 2025, the number of residents had declined to just 217 (Italian National Institute of Statistics, 2025).

Osidda was chosen as the subject of this study for several reasons. Its spatial characteristics are representative of typical hill villages in Sardinia, particularly in the north-eastern area. Its simple urban form

and building types facilitate analysis and modelling. Although under a depopulation process, the small but active remaining community signals a potential for effective reactivation actions and heritage conservation strategies. Finally, Osidda falls within climatic zone D, one of the two most prevalent climatic classifications in Sardinia (Repubblica Italiana, 1993), which makes the proposed methodology transferable to many other areas in the island.



Figure 1. The case study (the village of Osidda): (a) geographical framework; (b) photo of the historical centre (Bonapace Square). Sources: (a) graphic elaboration by authors from Google Earth; (b) authors.

This article has three specific aims. The first aim involves conducting an in-depth analysis and mapping of traditional urban and architectural features. This is achieved through a combination of archival and bibliographic research, direct analysis of the settlement's characteristics, and the urban stratigraphic method. This phase aims to identify the historical and cultural significance of the traditional fabric, guiding the subsequent phases, as it identifies the key areas to focus on.

The second aim focuses on microclimatic behaviour and thermal outdoor comfort conditions in the built environment, conducted through computational fluid dynamics and microclimate simulations on a typical critical summer's day. As a consequence of the identified issues in the microclimatic analysis, a set of mitigation interventions is proposed for the focus areas identified in the first phase. These solutions are selected through the integrated approach previously mentioned.

The third aim is the assessment of the effectiveness of the chosen mitigating interventions, through quantitative comparisons among the key variables determining the thermal outdoor comfort, providing valuable feedback on the potential mitigation interventions to foster sustainable urban reactivation and heritage conservation strategies.

The article is structured as follows. Section 2 presents the methodologies and tools used to analyse the historical urban fabric, as well as those adopted for investigating the urban microclimate and outdoor thermal comfort. Section 3 focuses on the results, in particular: Section 3.1 is devoted to the outcomes of the urban and stratigraphic analysis (first aim); Section 3.2 describes the digital model for the simulations and presents the analysis of the microclimate and human comfort in the current state (second aim); in Section 3.3, the outcomes from Sections 3.1 and 3.2 are used to select appropriate mitigation interventions critically; Section 3.4 is devoted to the assessment of microclimate and comfort conditions after the

implementation of the mitigation interventions (third aim). Finally, Section 4 is dedicated to conclusions and recommendations.

2. Methodology and Tools

As previously stated, in this work, the UMD methodology, developed by Chiri et al. (2020) in the context of an intervention to be built, has been adapted to the specific context of the revitalisation of an already existing historical village. This methodology can be summarised as a six-step process:

1. The current urban environment is analysed from an architectural and urban point of view, identifying both cultural values and critical issues.
2. A digital model of the built environment, featuring its meteorological characteristics, is developed.
3. The microclimatic behaviour of the current urban environment is assessed via numerical simulations to spot the related issues.
4. Mitigation interventions are selected through an interdisciplinary reflection, taking into account the constraints linked to the particular location and the historical value of the built environment.
5. Mitigation interventions are inserted into the digital model of the built environment, and their mitigative effectiveness is tested through new simulations.
6. If the results are satisfactory, the interventions transition from the preliminary design phase to the implementation phase. Otherwise, steps 4 and 5 are repeated, adapting the interventions until satisfactory results are obtained.

As this integrated methodology adopts a recursive and multidisciplinary design process combining the architectural and microclimatic perspectives, the tools used are useful from both points of view. In the following, the tools used to carry out the previously explained six-step process are presented.

The analysis of the historic village of Osidda from an architectural perspective began with the subdivision of the settlement into building units (BUs), structures sharing homogeneous typological features and functional autonomy (Fiorani, 2019). This preliminary articulation of the built fabric, based on the units previously identified in the Detailed Plan of the Historic Core (Comune di Osidda, 2015), enabled the launch of a systematic photographic campaign and direct analysis of the settlement's characteristics. The data gathering process focused on:

- The description of the historic urban space and architecture in terms of typology, volumetrics, construction techniques, materials, and use, along with observations on its current state of conservation and degree of transformation;
- The relationship between built and unbuilt spaces, considered in light of local geographic, topographic, climatic, social, and cultural conditions, as well as the functional, productive, and economic needs of the past;
- The interaction between natural and manufactured elements within the inhabited space, with particular attention to vegetation;
- The evolution of the urban space over time in response to emerging needs.

These collected data were then enriched with information from indirect sources, including:

- Historical cadastral maps from 1848, 1939, 1960, and 2014, which, through overlapping, enabled the classification of BUs into chronological phases and served as the basis for the stratigraphical analysis;
- Written reports from the 18th and 19th centuries, which provide population estimates for Osidda across the centuries and offer qualitative insights into the local climate and productive activities of the past (such as the *Fiscal Report* by de Zabarayn, 1701);
- The detailed plans for the historic centre (Comune di Osidda, 2002, 2015) are urban planning documents that include valuable information for the analysis of the historical urban fabric, such as the delimitation of the historic centre and the identification and classification of BUs;
- The Sustainable Energy Action Plan (Comune di Osidda, 2013), an urban planning document providing an overview of the municipality's energy consumption, emissions, and implemented energy retrofitting actions;
- The Sardinia Region's geoportal (<https://www.sardegnageoportale.it>), used to verify data through current and historical orthophotos and oblique aerial images, and to select the digital terrain model;
- Two monographs on Osidda, authored by local scholars, which focus on its history and territory (Di Cecilia, 1999; Zirottu, 2005);
- The Municipal Civil Protection Plan (Comune di Osidda, 2012) and the Regional Environmental Forestry Plan (Sardinia Autonomous Region, 2007, Attachment n.2) as the basis for the tree census within the settlement and its surrounding area;
- Historical photographs, offering visual documentation of the village between the 1930s and 1970s, which help reconstruct the past configuration of the urban fabric and its evolution;
- The knowledge of local communities, fundamental in small villages in Sardinia, where data from indirect sources is often limited, was gathered through informal conversations with residents, which, although not structured interviews, provided essential insights into the historical use of spaces, daily habits, and local environmental perceptions.

Given the quantity and heterogeneity of the data, and the need to manage them across multiple spatial and temporal scales, a structured digital database was essential. Geographic information systems (GISs) are one of the most widely used tools for territorial information management. They support, among other purposes, the handling of complex data related to cultural heritage and can be effectively employed throughout the various phases of a strategic design process (Deidda et al., 2010; Fiorino et al., 2009). QGIS was chosen for its ability to organise thematic data and to link descriptive attributes to specific elements of the urban fabric and the surrounding natural environment. Each one of the BUs was digitised as a georeferenced polygon and assigned a unique identification code. Then, the corresponding data collected was linked to it. These attributes were then used to generate thematic maps, providing a visual representation of the observed phenomena. This mapping not only supports the recognition of patterns but also stimulates the identification of both cultural values and critical issues associated with the studied heritage.

The use of QGIS also enabled the assignment of volumetric coordinates to each polygon, generating a three-dimensional model of the settlement that accurately reflects its spatial configuration. This 3D representation supported the development of a stratigraphic urban analysis aimed at tracing the settlement's evolution over time and identifying modern volumetric additions. This analysis reveals stratigraphic relationships among units, allowing for the establishment of relative and, when possible,

absolute chronologies. While this analysis is widely applied at the architectural scale (e.g., Brogiolo, 1988), the use of this approach at the urban scale remains limited (Fiorino, 2010). Even if previous applications typically treated façades as individual units, in this case, in addition to works to the façades, transformations can involve rear additions that fill internal courtyards or urban voids. For this reason, the approach was innovatively applied to the chosen urban context by considering each stratigraphic unit as a three-dimensional portion of a building, defined by coherent construction techniques, materials, and formal features that correspond to a specific historical phase.

The structured digital database allowed for the identification of numerous thematic layers in terms of built environment and public space: altitude profile of the terrain and the species and height of vegetation (entire area of interest); building typology and chronology, uses, number of storeys, masonry technique, roof type, eaves detail, window and door frames, ironworks, balconies and finishes, presence of distinctive architectural elements, degrees of transformation, and overall conservation status (built heritage); paving materials, retaining walls, steps, elevation changes, sidewalks, and ramps (public space).

The data gathered through the analysis previously described have been used to build the digital model for the simulations with the microclimate software ENVI-met (Bruse & Fleer, 1998). As previously mentioned in the Introduction, the use of microclimate software is often essential to obtain the spatial distribution of thermal outdoor comfort-related variables, from which predicted mean vote (PMV) maps can subsequently be calculated. ENVI-met is one of the most frequently used software for simulating the urban outdoor microclimate in complex urban and natural domains (Fabbri & Costanzo, 2020), taking into account the main involved variables, including the daily variations of the sun position according to the chosen geographical location. For these reasons, even with the typical limitations of numerical software, ENVI-met has been widely used as a useful tool capable of returning feedback on urban interventions (e.g., Dinić Branković et al., 2025; Fu et al., 2025; Zheng et al., 2025).

Moreover, accurate meteorological input data are essential to ensure physically consistent ENVI-met simulations (e.g., Ferrari et al., 2024). In the present work, meteorological data have been extracted from the ERA5 hourly dataset from 1940 to the present (Hersbach et al., 2023). This dataset by the European Centre for Medium-Range Weather Forecasts combines modelled and observed meteorological data into a globally complete and consistent dataset, including key parameters for the simulations such as air temperature, dew point temperature, wind speed and direction, and solar radiation. It is important to note that the use of the ERA5 dataset is supported by recent validation studies in the Sardinian region based on in situ measurements by Sirigu and Montaldo (2022) and by Montaldo and Corona (2024). These meteorological data were subsequently analysed to identify a representative day to be simulated. The extracted data have been used to define the simulated “typical critical day” (see Section 3.2 for details on the selection criteria).

3. Results and Discussion

3.1. Urban Fabric and Stratigraphic Analysis

From the QGIS database, it was possible to export visual thematic maps on the analysed topics. By comparing them, it was possible to identify cultural values and critical issues of the urban fabric. Figure 2 shows the thematic map illustrating the degree of transformation of the original building fabric. The degree

of transformation measures the extent of modifications each BU has undergone over the centuries, and it can be interpreted as a level of authenticity. The scale ranges from 0, indicating complete loss of authenticity (i.e., the building has been destroyed), to 5, representing full preservation, where the BU has not undergone any relevant transformation and retains its original form.



Figure 2. Visual map of the degree of transformation of the original building fabric.

By comparing this parameter with the thematic map of the conservation state (see Figure 1S, where “S” defines a figure in the Supplementary File) and the stratigraphic analysis of the built fabric (described further on; see Supplementary File, Figures 2S, 3S, and 3), it becomes evident that the buildings which are both the oldest and least altered are often in the worst condition. On the other hand, older buildings that have been significantly modified, whether for structural or functional reasons, are generally in better shape. This highlights a correlation between usability and preservation: Buildings that have been adapted over time, even through inconsistent or unplanned changes, tend to be better maintained due to their continued use and care. However, more than one-third of the traditional masonry buildings, which represent half of the total building stock, are in an advanced state of decay. The level of degradation has become so critical that public access to some parts of the historic core has been restricted for safety reasons. Nevertheless,

targeted conservation efforts have played a key role in preserving several traditional structures, currently in a very good state of conservation. The most extensive among these were the LEADER I and II European initiatives of the 1990s, which, in the case of Osidda, aimed to develop a “distributed” hotel by repurposing 13 traditional buildings. Thanks to this initiative, one of the most historically preserved areas is Delogu Square (Figure 1), surrounded by historical buildings once owned by the influential Delogu family. Today, while some of these buildings have been carefully preserved, others remain in a state of ruin. Nevertheless, their condition does not jeopardise the square’s historical character, which continues to express a strong sense of identity.

The LEADER European initiatives enriched the already existing offer of services. Several public services are available within the village, most of which are located in the historic core. They are primarily concentrated around Bonapace Square and Dei Caduti Square, two interconnected, wide open spaces (Figure 1). This area hosts essential services such as the town hall, the post office, a café, and the ethnographic museum. Several accommodation facilities are located near Bonapace Square and are a part of the aforementioned distributed hotel. Except for a few contemporary additions (such as the town hall, built in reinforced concrete; the prefabricated wooden structure of the café; and the modern granite paving of Bonapace Square), these spaces retain a connection with the historical nucleus. This is particularly due to the fact that most of the services are accommodated within traditional buildings.

The urban analysis led to the selection of three focus areas that serve as case studies in the subsequent phases of the research. The first is Delogu Square, a historically significant square whose identity is well preserved (as visible from Figure 2, the area is mostly characterised by 3, 4, and 5 values of the index, which refer to the most intact and authentic buildings), yet whose full potential remains unrealised due to the presence of disused and derelict buildings. Moreover, its perception as an abandoned and neglected place jeopardises its role as a social attractor. Although Bonapace Square and Dei Caduti Square, the second and third focus areas, contain most of the services offered within the village, they are not used as a gathering place in everyday life. For this reason, they can be considered potential centres for the future social life of the village.

These spaces have already been part of a conservation and enhancement strategy called INCANTO (Cherchi & Fiorino, 2023). This initiative, consistent with recent guidelines for the regeneration of small villages promoted by the Italian Government (Repubblica Italiana, 2017, 2021), adopts a “design for all” or “universal design” approach (see, for example, Ormerod & Newton, 2005), aiming to promote inclusivity and accessibility for all, fostering sustainable urban reactivation, advancing heritage conservation strategies, and supporting social cohesion.

Figure 3 presents the three-dimensional chronological reconstruction of the urban stratigraphy in the surroundings of the focus areas. The stratigraphic analysis conducted in these areas allowed for the reconstruction of the settlement’s evolution over time. The urban fabric was divided into stratigraphic units, which were grouped into three main chronological phases: the first includes buildings constructed before 1939, the second comprises additions made between 1939 and 1960, and the third includes structures built after 1960. The years 1939 and 1960 were selected as reference points due to the availability of cadastral maps from those years, which provide reliable and geometrically accurate information on urban morphology. By contrast, the 1848 cadastral map was excluded from the analysis because it lacks geometric precision, making superimposition with later maps unreliable. The year 1939 was also chosen as a meaningful

reference as by that time the settlement had reached a mature urban form, structurally comparable to the one still visible today.

The first chronological phase was further subdivided based on close examination of specific buildings. In particular, features such as masonry discontinuities, the use of different construction techniques, and varying degrees of material degradation across different parts of the same structure suggest that some buildings were not built in a single phase, but rather in two or more successive stages, all occurring before 1939.

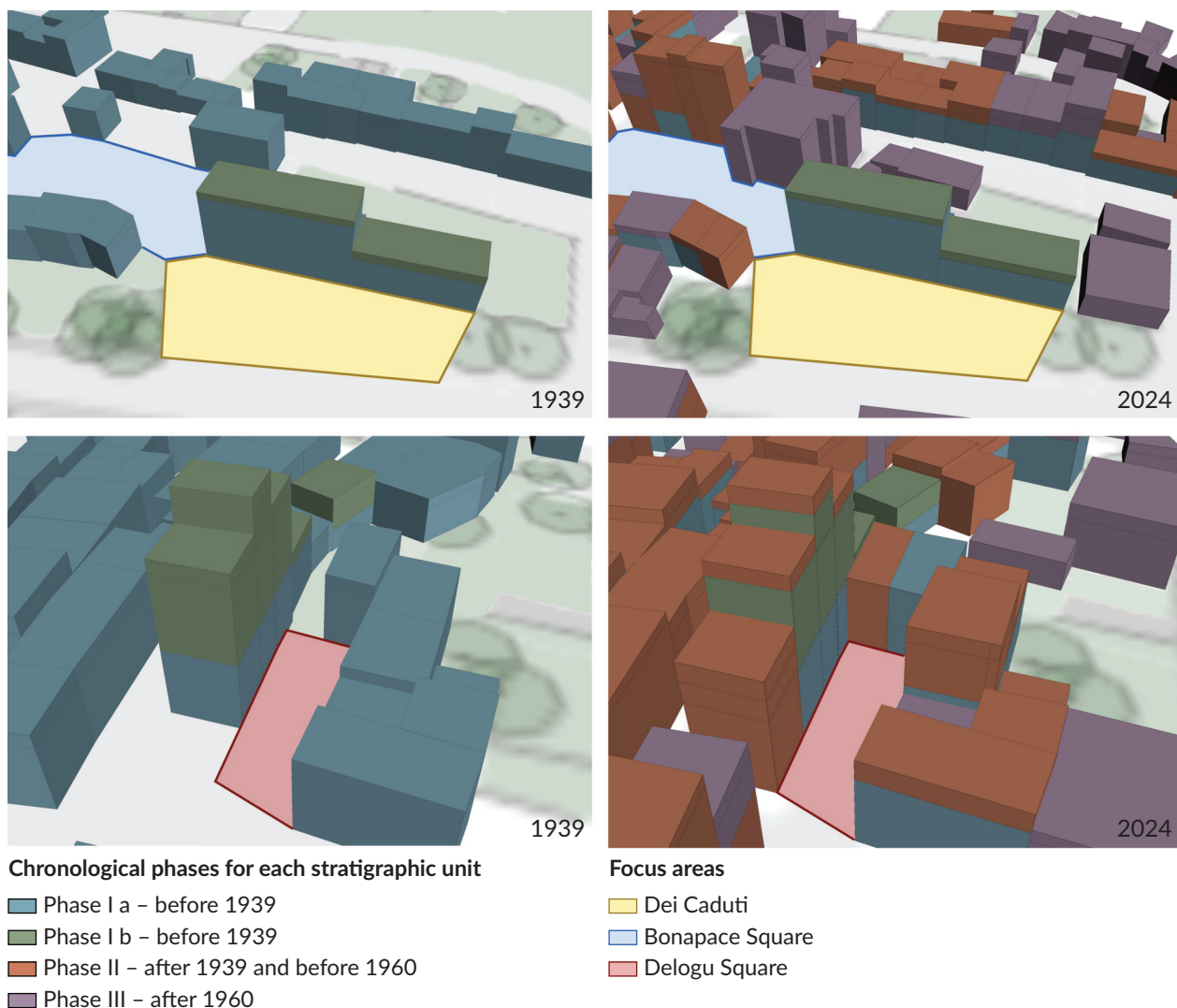


Figure 3. The three chronological phases of the stratigraphic units, from the most ancient to the most recent. The figures on the left represent the aspect of the built heritage in 1939 (comprising phases I a and I b); the figures on the right represent the present situation.

The second phase was identified through the comparison between the 1939 and 1960 cadastral maps and includes additions still based on traditional techniques, such as granite masonry or roofing systems typical of the local building culture. In contrast, the third phase consists of more recent constructions, characterised by the use of industrial materials and contemporary construction methods.

In Figure 3, the left column illustrates the state of the built environment in 1939, while the right column shows the present situation, allowing for a visual comparison between the traditional settlement and its present-day urban morphology. Although new constructions have occupied former courtyards and open spaces, and some existing buildings have been vertically extended or modified in typology (e.g., transformed from pitched to flat roofs), the original layout of the settlement has remained largely intact.

All focus areas were already present in the 1939 cadastral map. Although Dei Caduti Square was not explicitly named until the 1960 map, its boundaries are recognisable in the 1939 documentation. This continuity suggests that all the squares have preserved both their spatial configuration and their role as public gathering spaces over time. The activity conducted in this stage corresponds to the first step of the methodology described in Section 2.

3.2. Analysis of the Microclimate and Outdoor Thermal Comfort in the Present Situation

Following step two of the methodology, the data gathered through the analysis described in Section 2 have been used to build the ENVI-met digital model for the simulations.

This model measures 515 m in length, 196 m in width, and 92 m in height, which frames the historical core of the village. A cubic grid cell with a side length of 1 m was selected as the basic unit for mesh generation. A telescoping factor of 20% was applied to have only 64 cells instead of 92 cells in the vertical direction, for a total of 6,460,160 cells. The model includes the digital terrain model (Figure 4a) and was rotated 20° counter-clockwise to better align with the area of interest. After preliminary simulations, 29 additional cells were added to each lateral boundary to ensure numerical convergence.

The QGIS plugin “Geodata to ENVI-met” was used to export into ENVI-met the building heights and construction materials for each building, both for the roof and vertical walls, and the material properties of vehicular and pedestrian infrastructures, soils, and vegetation.

Regarding the meteorological input data, the choice of the particular day to be simulated was based on the analysis of ERA5 data from 1940 to the present (Hersbach et al., 2023; see Section 2). In the present study, a “critical day” is defined as any day that combines tropical nights and hot days. The analysis of the critical day trend in Osidda shows a significant upward trend, from only one critical day in 1940 to 14 in 2024. The daily temperature and humidity evolution on these 14 critical days (Figures 4b and 4c) highlights a substantial variability. It is relevant to note that these 14 days are concentrated in 33 days, meaning that, during this period, almost half of the days are critical ones.

Among the identified days, July 12, 2024 (in black in Figures 4b and 4c) was selected as the “typical critical day,” as it best represents the daily trend of air temperature and relative humidity. This day is also characterised by the typical summer wind conditions in Osidda (light winds blowing from the western sector). Consequently, the day of July 12, 2024, was chosen for the simulations: The start time was 5:00, one hour before sunrise in Osidda on that day, and the simulation comprised 24 hours, ending the following day at 5:00.

A constant wind speed of 1.15 m/s and a wind direction of 271.50 °N at an altitude of 10 m, as well as the air temperature and relative humidity of July 12, 2024 were set as boundary conditions at the inflow border of the model (Figure 4).

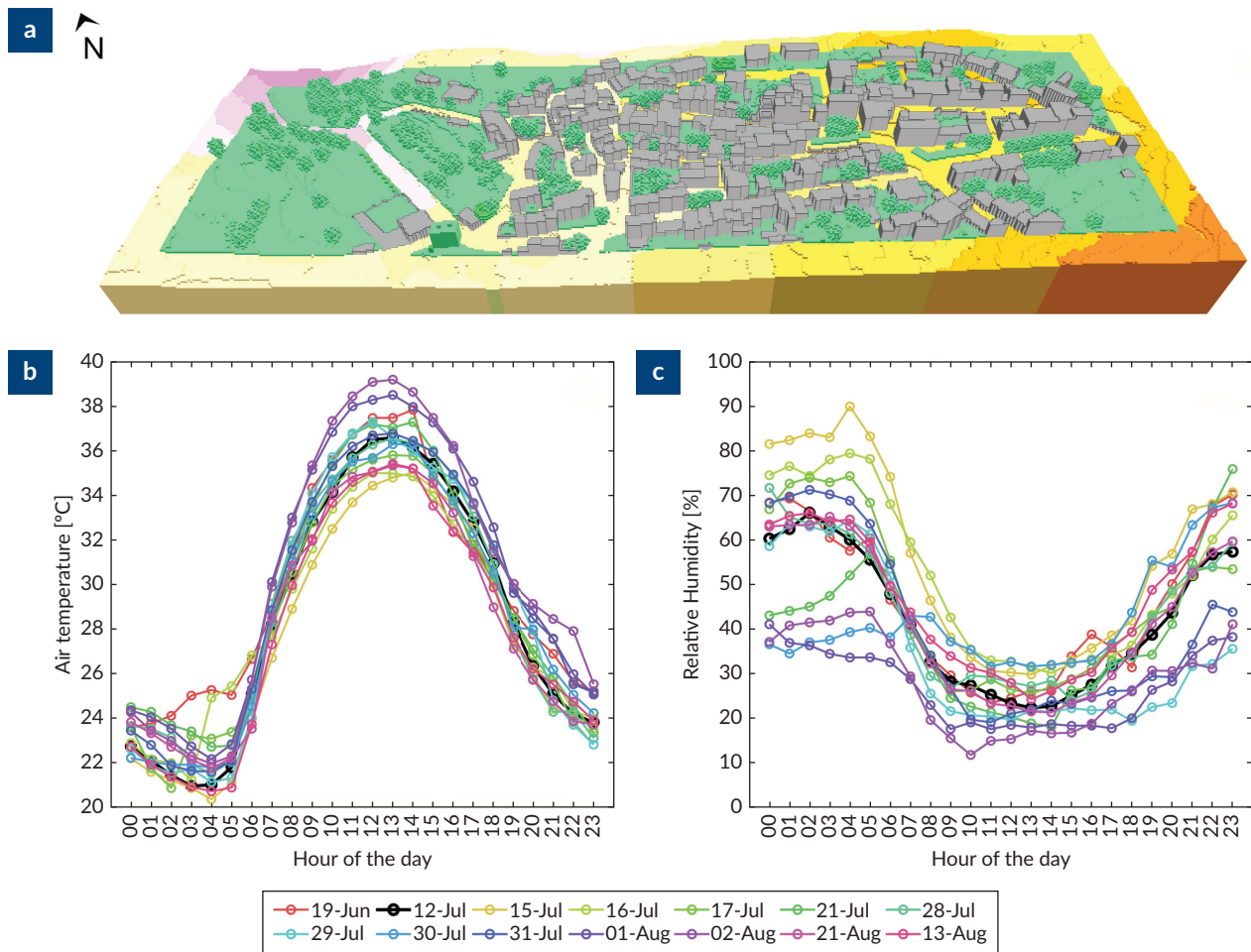


Figure 4. Model and input data: (a) three-dimensional model of Osidda (buildings are shown in grey and vegetation in green; the level of the underlying terrain topography starts from dark pink, for the lowest elevation, and then ranges, as the level increases, to light pink, light yellow, and orange, indicating the highest elevation); (b) air temperature (°C) and (c) relative humidity (%) during the critical days in Osidda in 2024 (in black the values for the simulated typical critical day).

The simulation results were post-processed using “Biomet,” a tool integrated within ENVI-met that calculates human thermal comfort indices based on the model’s atmospheric outputs. As previously stated, the PMV index was used.

The PMV calculation was tested for four categories, representing the most relevant age classes among the inhabitants of Osidda: (a) elderly female (80 years old); (b) elderly male (80 years old); (c) adult female (52 years old, the average female population age); and (d) adult male (45 years old, the average male population age). All categories shared the same body position (standing), walking speed (1.21 m/s), and summer clothing parameters. The results showed that the first category (elderly females, 80 years old) experienced the highest level of thermal discomfort, and consequently, it was selected as the reference case.

In Figure 5, the maximum hourly PMV values during the analysed day are shown. The highest PMV value is found at 14:00, and consequently, it was chosen as the reference hour (the most critical) for the following discussion.

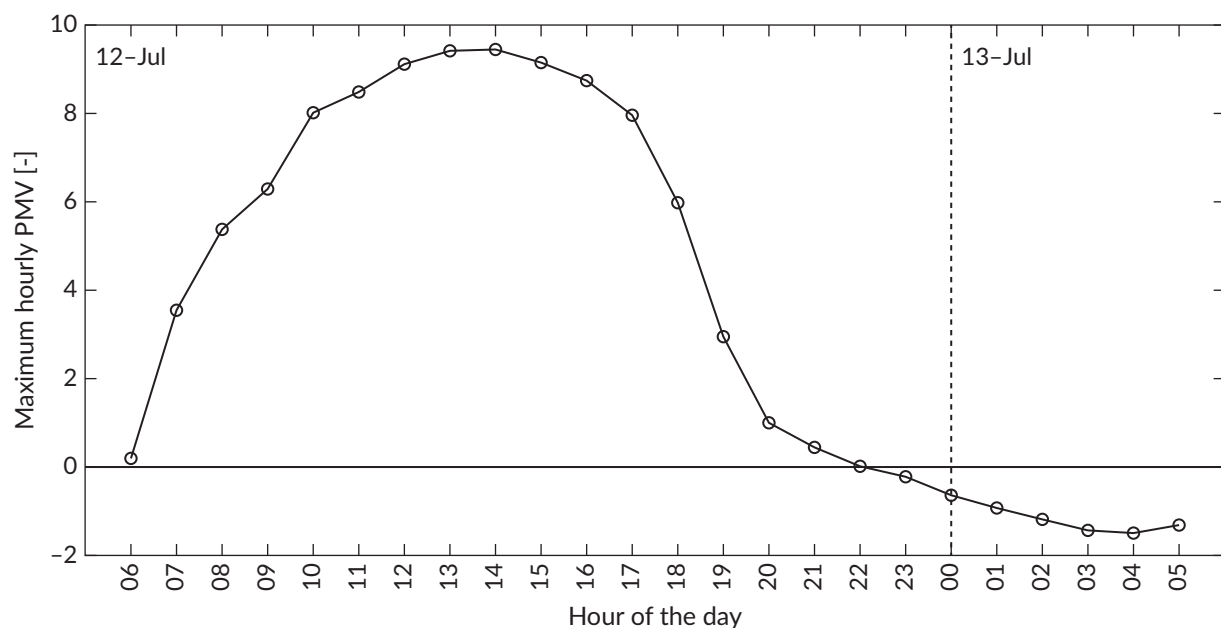
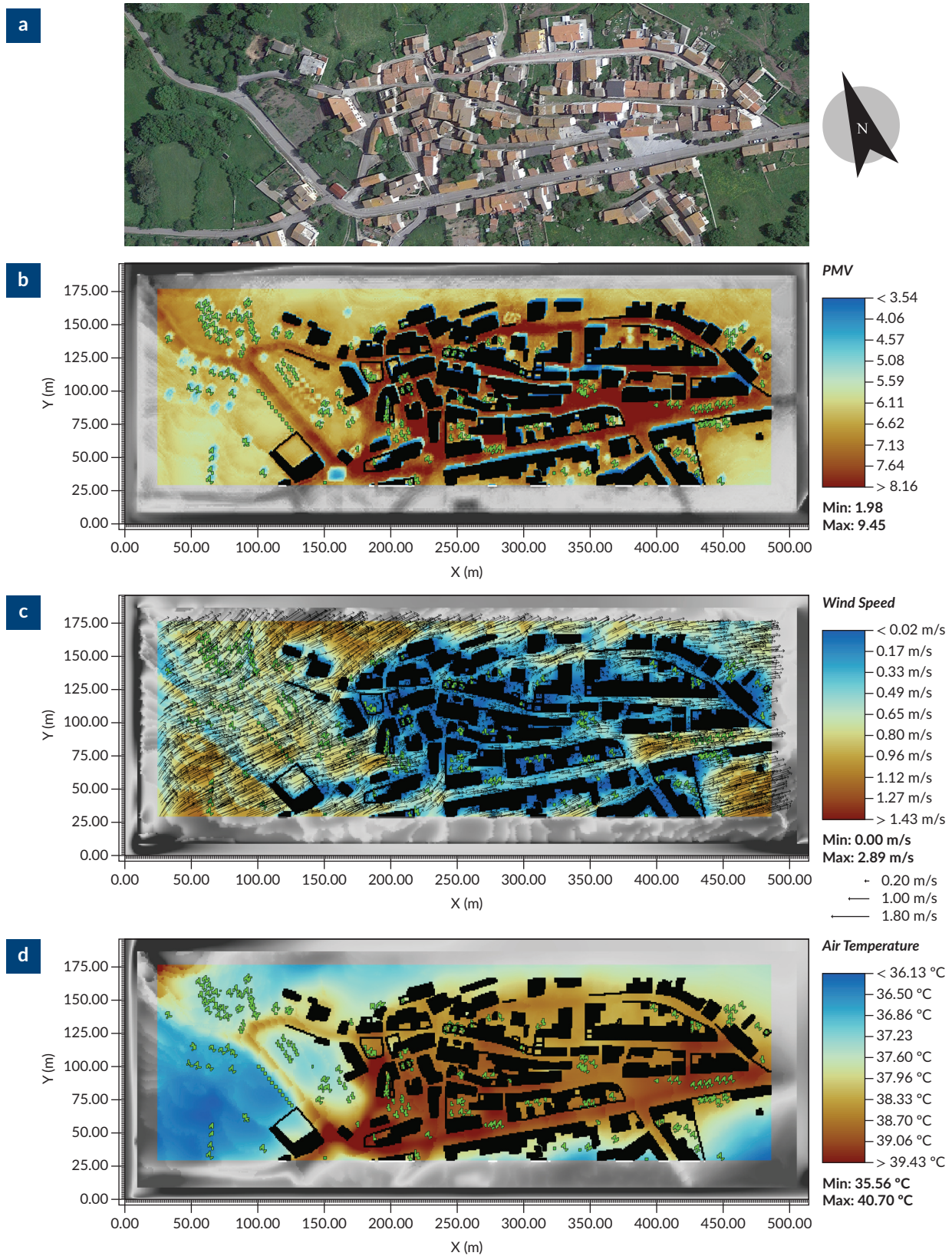


Figure 5. Maximum hourly PMV [-], at 1.5 m above ground, during the simulated day. Note: [-] means that the quantity is unitless.

In Figure 6, the analysis of the PMV and its main drivers, at 1.5 m from the ground (i.e., at pedestrian level), in the present situation is shown. In particular, in the first panel (Figure 6a), an orthophotography of the analysed area is reported. The borders of Figures 6b to 6g are in grey, being the cells added to ensure the convergence of the simulations. In Figure 6, the values of each quantity are represented in colours according to the colorbar on the right, the buildings in black, and the vegetation in green.

The PMV in the present situation is illustrated in Figure 6b. In general, as all the values are positive and significantly higher than zero, the perception of people frequenting outdoor spaces during the afternoon is one of discomfort due to the extremely hot conditions, resulting in a high degree of physiological stress caused by the heat. The highest values are recorded inside the built area, while moving away from it, the PMV values are lower, with the sole exception of the provincial access road to Osidda, visible on the left and built in asphalt. Within the built environment, the lowest values are recorded in shaded areas, due to the position of the sun at 14:00. On the other hand, the daily variation of PMV (Figure 5) shows an acceptable condition from 20:00 until 5:00 (with values in the range from -2 to $+2$). However, from sunrise until sunset, the PMV values always exceed $+3$, highlighting that the previously mentioned thermal stress condition is always present during the hours of sunshine. Thus, during daylight hours, the built environment worsens outdoor thermal comfort. In contrast, at night, it contributes to improving thermal perception throughout the village. These results suggest that the compact urban form and construction materials of Osidda provide effective protection from nighttime heat loss. This behaviour is consistent with a traditional design logic oriented toward mitigating cold conditions, which, in the past, were the prevailing climatic stressor in the Northern hilly areas of Sardinia.

In the following, the main drivers of comfort in the present situation will be analysed.



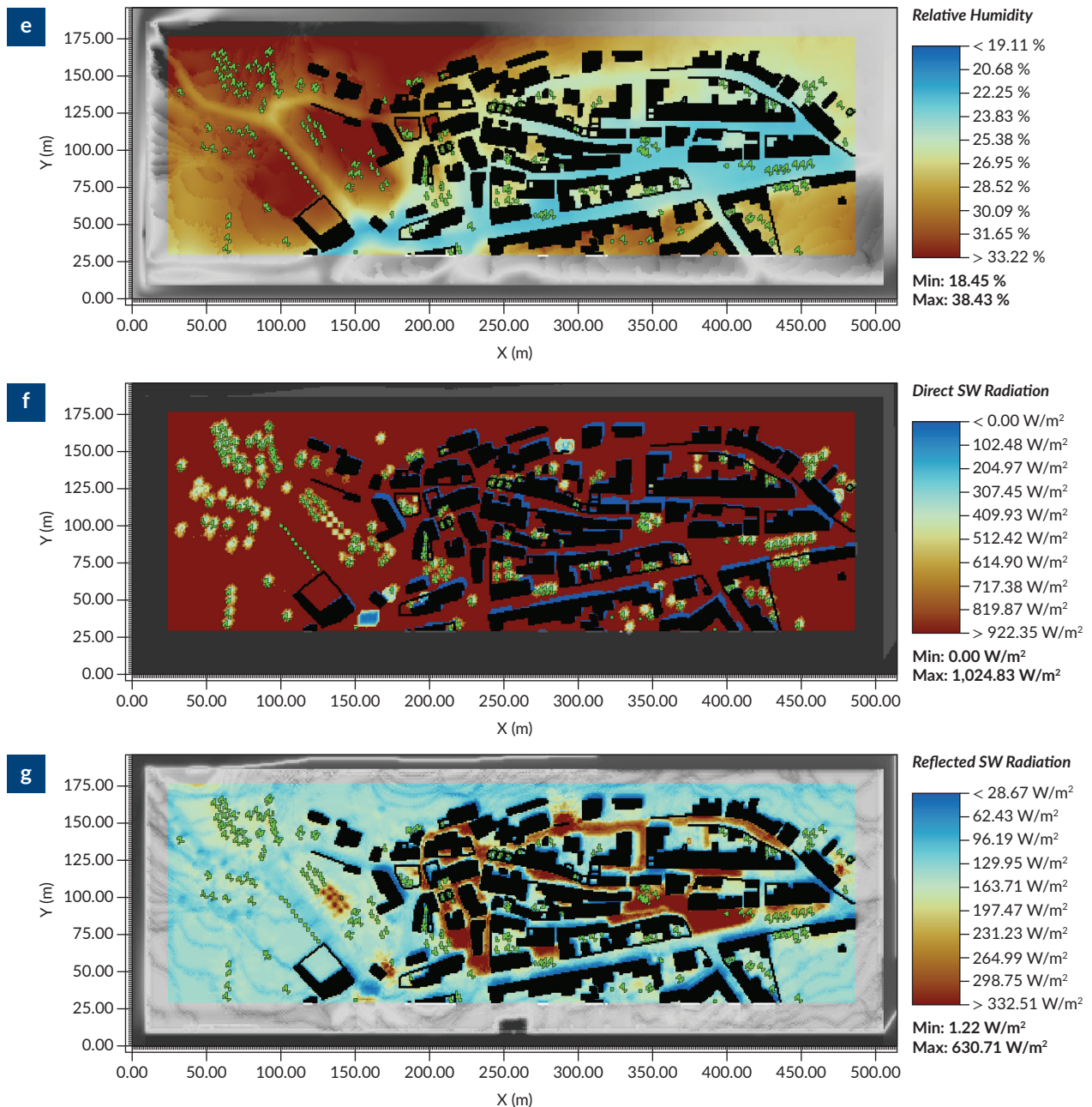


Figure 6. Microclimate analysis of the present situation at 14:00 of July 12, 2024: (a) orthophoto of the analysed area; (b) PMV [-]; (c) wind speed (m/s) and direction; (d) air temperature (°C); (e) relative humidity (%); (f) direct solar radiation (W/m²); (g) reflected solar radiation (W/m²). Notes: All values at 1.5 m above the ground; SW = short wave; [-] means that the quantity is unitless. Sources: (a) Google Earth; (b)–(g) authors.

The absolute value and direction of the wind speed, which drive the ventilation of the built environment, are shown in Figure 6c: The colours (together with the length of the vectors) represent the absolute value of the speed, while the orientation of the vectors highlights the direction of the wind. The critical summer days in Osidda are characterised by poor ventilation: In this case, the highest wind speed values are everywhere less than 1.5 m/s and are strongly attenuated inside the built space, highlighting its sheltering function.

Figure 6d shows the air temperature in Osidda. Even though it is a small village, an evident urban heat island phenomenon can be spotted, as the temperature inside the built environment tends to be between 2 °C and 4 °C higher than outside. To highlight that the outdoor thermal comfort is a complex phenomenon not only related to the air temperature, it is worth noting that the areas with the highest air temperature do not correspond to the areas of highest PMV (Figure 6b).

In Figure 6e, the relative humidity is presented; as previously shown, the summer critical days in Osidda feature low humidity levels during the day, with almost all the village tending to have values more than 10 percentage points lower than the surrounding area.

Figures 6f and 6g show, respectively, the direct and reflected solar radiation. Even if the values of the direct radiation are very high everywhere, as expected on a summer sunny day without clouds (except where buildings or trees provide shading), the spatial distribution of the reflected radiation is particularly interesting. The values of the reflected radiation are very high where the granite has been used to pave the squares and to cover the building façades, resulting in total radiation values (direct plus reflected) equal to or even higher than 1,360 W/m² (i.e., the energy transported by solar radiation to the ground at noon at the equator), with a consequent deterioration of the thermal outdoor comfort.

The analysis of the microclimate and outdoor thermal comfort in the present situation, which corresponds to the third step of the methodology described in Section 2, highlights that the most relevant factor influencing the PMV is the solar radiation.

3.3. Selection of the Mitigation Interventions

The results of the analysis of the historic urban fabric (Section 3.1) led to the selection of three focus areas: Delogu Square, Bonapace Square, and Dei Caduti Square, all of which are potential centres for the future social life of the village. According to step four of the methodology, to select the mitigation interventions in these squares, architectural and microclimatic factors, as well as the costs of installation and maintenance, were taken into account. Delogu Square, being entirely pedestrian, offered more design flexibility. In contrast, Bonapace Square and Dei Caduti Square had to remain accessible to vehicles.

The microclimate analysis (Section 3.2) revealed that, in this study case, wind is not the primary contributor to thermal discomfort. Moreover, the historical value of the built environment did not allow for deep modifications. For these reasons, most wind-oriented geometrical strategies (excluding shading, as discussed in Section 1) were considered unsuitable. Instead, direct and reflected solar radiation emerged as the most relevant driver of the PMV. Therefore, the use of shading strategies was considered the most appropriate, having the effect of reducing both types of solar radiation. Additionally, as high humidity was not a problem (Figure 6e), greening and evaporative cooling strategies were also considered suitable.

Therefore, the final choices for the mitigation interventions included a geometrical shading through sun sails (removable during the night or winter) in Delogu Square (Figures 7 and 8), and greening shading through pergolas, coupled with evaporative cooling with sprays, in Bonapace Square (Figure 7) and Dei Caduti Square (Figure 7 and 8). Deciduous plants were chosen for the pergolas, to allow winter sunlight to pass through. This choice also allowed a quantitative comparison between the mitigation capabilities of different interventions.

Following step five of the methodology, each proposed intervention was implemented and parameterised in the ENVI-met digital model. The sun sails installed above the pedestrian area in Delogu Square were modelled as a suspended building element, with assigned values (i.e., absorption, transmission, reflection, emissivity, specific heat, thermal conductivity, density) derived from experimental data reported by Zhao et al. (2024). The element was designed to extend from the nearest lane to guide the visitor towards the square. At the same time, the shape followed the perimeter of the bordering buildings, with 1 m of distance from them to avoid interactions with the historical surfaces and to allow ventilation. The result was a light impermeable structure, composed of two adjacent parts positioned at different elevations to adapt to the variation of roof heights of the buildings constituting the limits of the square.

In Bonapace Square and Dei Caduti Square, shading was implemented through green-covered pergolas in two configurations: with and without water spray systems. Moreover, to assess the impact of vegetation density on microclimate, different leaf area density (LAD) values, i.e., the one-sided leaf surface area per unit volume of canopy (m^2/m^3), were assigned to the plants covering the pergolas. The two values used ($0.15 \text{ m}^2/\text{m}^3$ and $0.5 \text{ m}^2/\text{m}^3$) represented, respectively, the foliage density expected shortly after installation and after several years of growth. This enabled an evaluation of whether it is preferable to invest from the outset in more expensive but mature vegetation, rather than in younger plants.

Both pergolas had a height of 3.5 m and simple geometrical configurations (Figure 7). The one in Bonapace Square was a 30 m-long, 4 m-wide rectangle with a covered area of 120 m^2 , designed to cover an area already arranged as a sitting area. The one in Dei Caduti Square was L-shaped, with a long side of 30 m, a short side of 7 m, and a width of 4 m, with a covered area of around 150 m^2 . Such a configuration was thought to serve

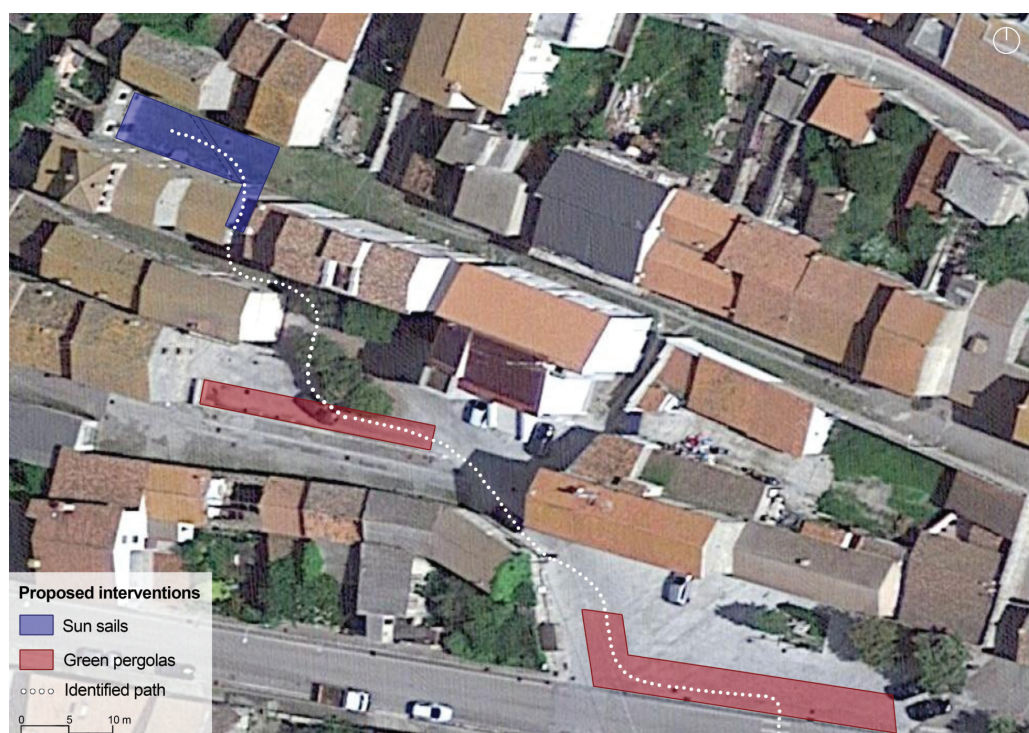


Figure 7. The positioning of the proposed interventions within the three focus areas and the identified path that they form (Dei Caduti Square, Bonapace Square, and Delogu Square). Source: graphic elaboration by authors from Google Earth.

as a separation between Garibaldi Avenue, a fast-moving road, and the square, enabling pedestrians to feel safer. Moreover, the L-shape was intended to guide the visitors towards the historic core of the village.

The water spray system was modelled using point sources representing water nozzles, with each source positioned at 2.5 m above the ground level. This value was selected based on findings by Zhao et al. (2024), who identified 2.3 m as the optimal spray height for cooling pedestrians at 1.5 m, but it was slightly adjusted to 2.5 m to align with the model's vertical mesh resolution. The sources were arranged in linear rows, with a spacing of 1 m between adjacent sources and 2 m between the two rows. A total of 60 sources were installed beneath the pergola in Bonapace Square, while 79 were placed under the pergola in Dei Caduti Square. Each source operated at a flow rate of 2 g/s, consistent with the findings of Zhao et al. (2024), resulting in a total water demand of approximately 1 m³/h. This raised practical concerns about resource consumption, particularly in a region like Sardinia, which frequently faces drought conditions. This consideration motivated the decision to run the simulations also without the evaporative cooling system, to weigh the comfort benefits against water consumption and to identify the most sustainable configuration (i.e., with or without evaporative cooling).

A dedicated simulation was conducted for each of the proposed configurations, all keeping the sun sails in Delogu Square, resulting in a total of four simulations, whose effectiveness in terms of comfort improvement will be discussed in the next section.

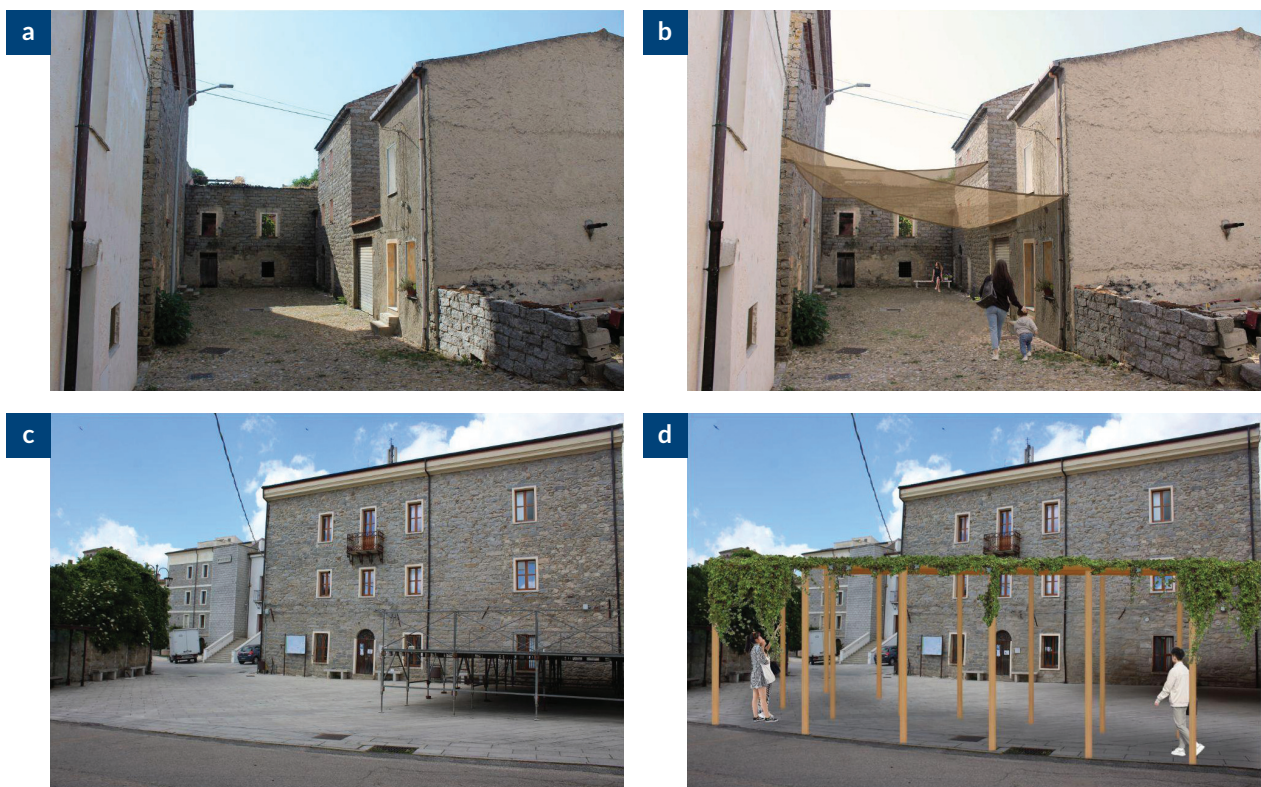


Figure 8. A visual representation of the mitigation interventions: (a) Delogu Square before the intervention; (b) Delogu Square after the intervention; (c) Dei Caduti Square before the intervention; (d) Dei Caduti Square after the intervention.

3.4. Analysis of the Microclimate and Outdoor Thermal Comfort After the Mitigation Interventions

To evaluate the effectiveness of the selected mitigation strategies, as noted in step six of the methodology, Figure 9 (where the values of each quantity are represented in colours according to the colour bar on the right, the buildings in black, and the vegetation in green) shows the percentage difference in PMV between the current scenario and each proposed intervention. In particular:

- Figure 9a highlights the focus areas of the study.
- Figure 9b illustrates the effect of the sun sails in Delogu Square and pergolas with the low LAD in the other two squares.
- Figure 9c represents the same situation as Figure 9b, but with the high LAD.
- Figure 9d shows the sun sails and pergolas with the low LAD and water sprays.
- Figure 9e represents the sun sails and pergolas with the high LAD and water sprays.

Since the sun sails' features in Delogu Square remain constant, its outcomes are identical across all scenarios: a consistent PMV reduction of over 50%, reaching peaks of more than 60%. This confirms its high effectiveness in this context.

In Bonapace and Dei Caduti Squares, the basic pergola setup (low LAD, no sprays; Figure 9b) already achieves some thermal comfort improvements (with PMV reductions of up to 10.66% and 17.76%, respectively). Still, their effectiveness is lower than that of the sun sails. Increasing the LAD (Figure 9c) enhances performance, especially in Dei Caduti Square, where PMV reductions reach levels previously seen only at peak points.

Adding water sprays (Figure 9d) to the basic pergola setup improves both the magnitude and extent of PMV reduction, thanks to the diffusion of moisture in the surrounding air. These results confirm the benefits of combining shading and evaporative strategies, as supported, among others, by Zhao et al. (2024).

The results obtained with the pergolas with the high LAD and water sprays, which compose the most mitigative potential setup, are illustrated in Figure 9e. Compared to Figure 9d, there is a slight increase in the improved comfort area and, more notably, an expansion of the areas showing a PMV peak reduction (around 17.76%), particularly in the Bonapace Square area. Compared to Figure 9c, there is a broader mitigated area in both Bonapace Square and Dei Caduti Square, as well as a significant increase in the mitigation effectiveness in Bonapace Square.

In summary, geometrical shading using sun sails proved to be the most effective strategy in this specific urban context. Shading through vegetation was also beneficial and, as expected, more efficient when using plants with higher LADs. The addition of an evaporative cooling technique via the use of sprays leads to a higher PMV reduction in both cases. However, it raises sustainability concerns: A water consumption of approximately 1 m³/h can be intolerable in Sardinia, due to drought problems. Consequently, the configuration with the higher LAD and without the sprays can be considered as the most suitable in this specific case.

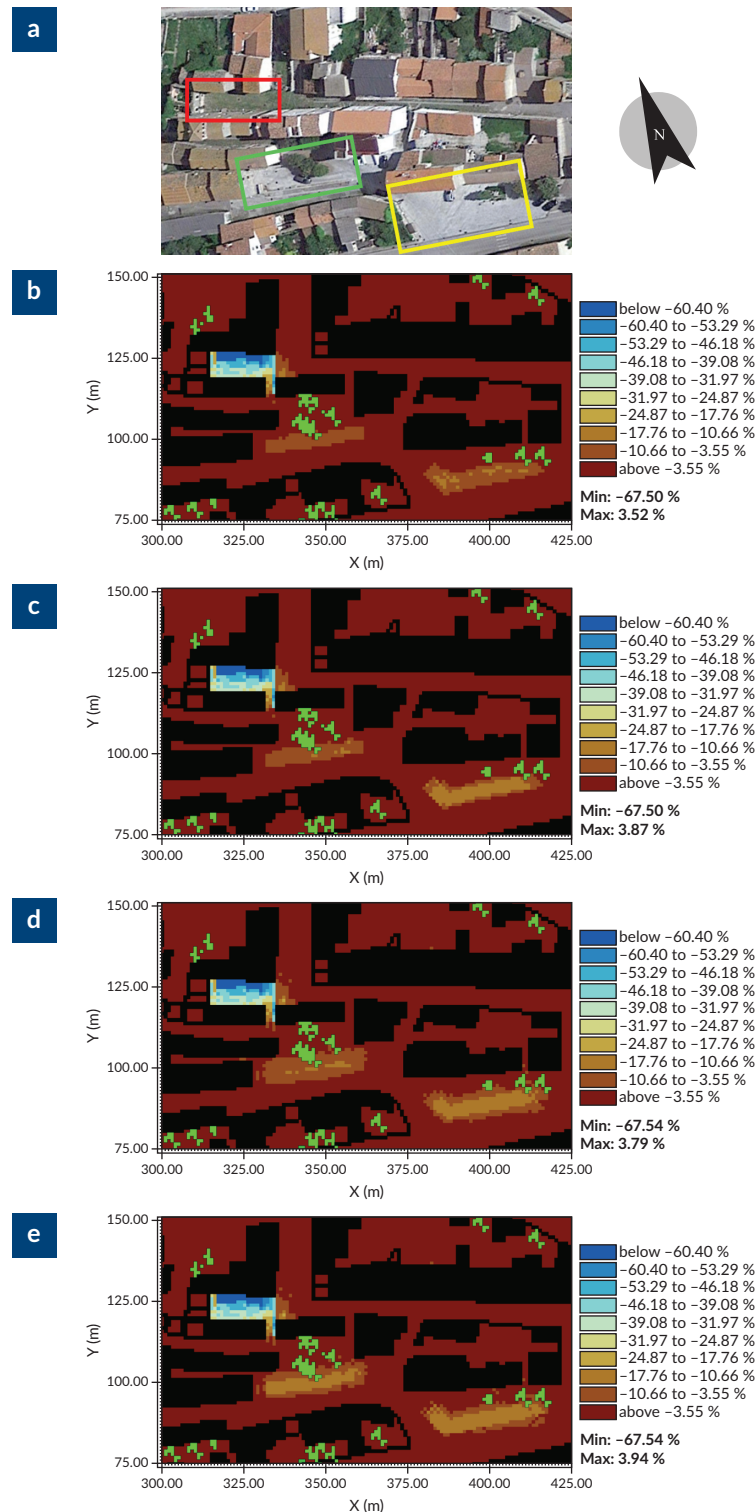


Figure 9. Microclimate analysis after the mitigation interventions at 14:00 on July 12, 2024: (a) orthophoto of the analysed areas; (b) relative difference between PMV in the present situation and after intervention of sun sails and pergolas ($LAD = 0.15 \text{ m}^2/\text{m}^3$); (c) relative difference between PMV in the present situation and after intervention of sun sails and pergolas ($LAD = 0.5 \text{ m}^2/\text{m}^3$); (d) relative difference between PMV in the present situation and after intervention of sun sails, pergolas ($LAD = 0.15 \text{ m}^2/\text{m}^3$), and sprays; (e) relative difference between PMV in the present situation and after intervention of sun sails, pergolas ($LAD = 0.5 \text{ m}^2/\text{m}^3$) and sprays. Note: All values at 1.5 m above the ground. Sources: (a) graphic elaboration by authors from Google Earth; (b)–(e) authors.

To support this conclusion, in Figure 10 (where the values of each quantity are represented in colours according to the colour bar on the right, the buildings in black, and the vegetation in green), this setup is compared with the current state, in terms of relative difference (in %) in the main PMV drivers, specifically: wind speed (Figure 10b), direct solar radiation (Figure 10c), and reflected solar radiation (Figure 10d). Wind speed (Figure 10b) is not significantly affected by the pergolas, due to their permeability. Although the sun sails have a stronger shielding effect, they still allow ventilation from above, thanks to the 1 m distance from the surrounding buildings (this explains the positive velocity peaks in Figure 10b). Air temperature differences are minimal (see Figure 4Sb in the Supplementary File), with reductions up to -0.3% under pergolas and -1.1% under sun sails. Humidity changes are also modest (see Figure 4Sc in the Supplementary File), increasing up to $+0.67\%$ under pergolas and slightly above $+2.5\%$ under sun sails. The most impactful PMV driver is direct solar radiation (Figure 10c), characterised by reduction peaks of -36.7% under pergolas and -100% under sun sails, as well as reflected radiation (Figure 10d), with reductions of -35% under pergolas and -96.86% under sun sails.

To conclude, in this case study, as expected, when the mitigation strategies were selected, the dominant driver in the PMV improvement was the solar radiation reduction.

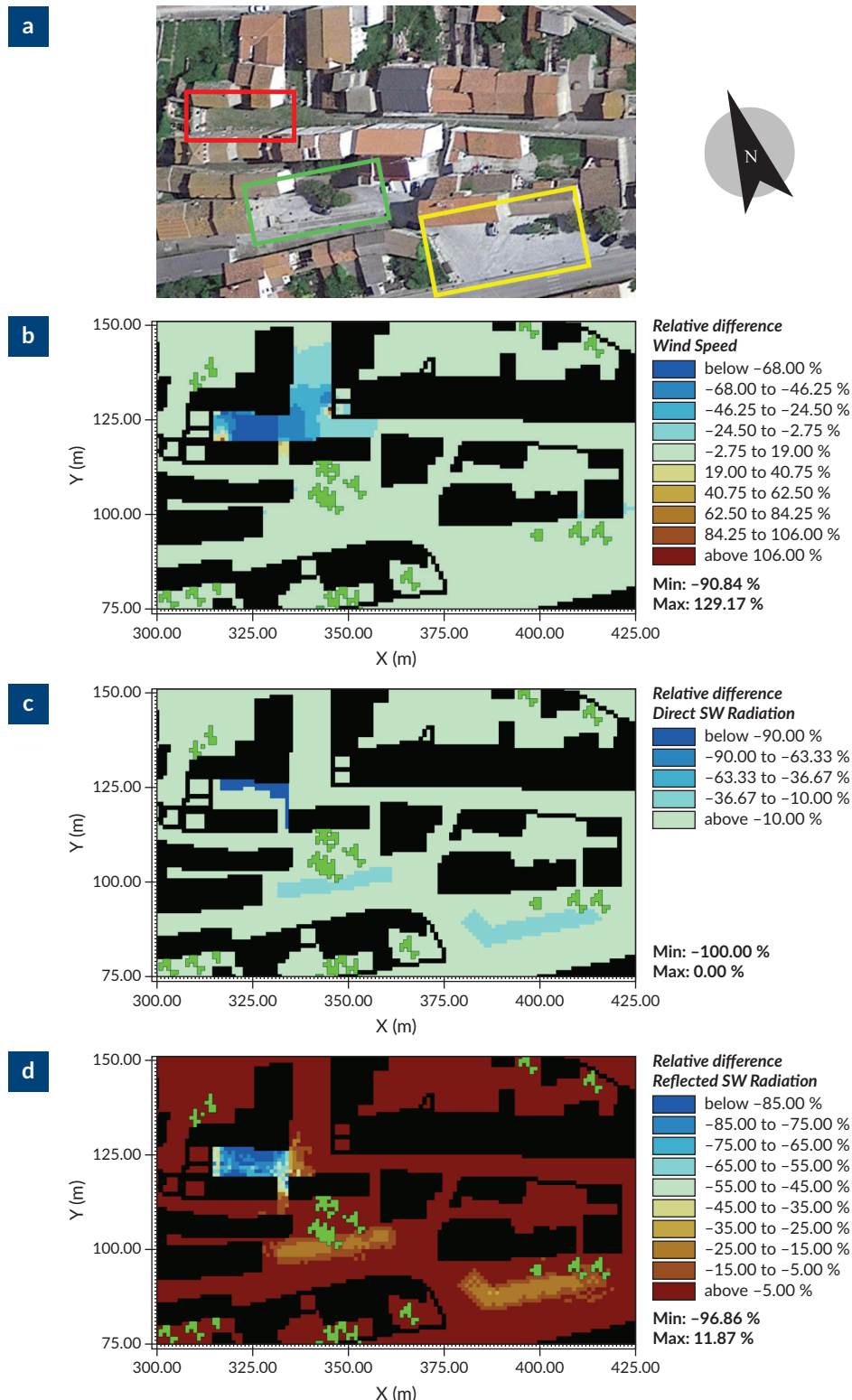


Figure 10. Microclimate analysis after the mitigation interventions ($LAD = 0.5 \text{ m}^2/\text{m}^3$, no spray) at 14:00 of July 12, 2024: (a) orthophoto of the analysed area; (b) relative difference between the microclimate driver of wind speed before and after the intervention; (c) relative difference between the microclimate driver of direct solar radiation before and after the intervention; (d) relative difference between the microclimate driver of reflected solar radiation before and after the intervention. Note: all values at 1.5 m above the ground. Sources: (a) graphic elaboration by authors from Google Earth; (b)–(e) graphic elaboration by the authors.

4. Conclusions and Remarks

This contribution explored the application of the integrated UMD methodology to the in-depth analysis of historical urban contexts and their microclimatic dynamics, focusing on the case study of the small historical village of Osidda. Three main objectives were identified:

- The elaboration of an in-depth urban fabric and stratigraphic analysis, through the direct analysis of the settlement's characteristics (a combination of archival and bibliographic research), and the urban stratigraphic method, permitting the identification of the areas of historical and cultural significance, as well as the focus intervention areas.
- The assessment, through computational fluid dynamics and microclimate simulations, of microclimatic behaviour and thermal outdoor comfort conditions in the local built environment on a typical critical summer day; the identified issues lead to the selection of a set of mitigation interventions for the focus areas, selected through the integrated UMD methodology.
- The assessment of the effectiveness of the selected mitigating interventions, through quantitative comparisons among the key variables of thermal outdoor comfort, to evaluate the capability of the mitigation interventions to foster sustainable urban reactivation and heritage conservation strategies.

The results of the urban fabric analysis identified cultural values and critical issues. Traditional masonry buildings, which represent half of the total building stock, are generally in better condition thanks to modifications, even when using inconsistent building techniques and industrial materials, as they ensure ongoing use and maintenance. Although some abandoned historical buildings are in an advanced state of decay, often reaching structural instability, others are well preserved thanks to past interventions and now host various services. The urban fabric analysis led to the identification of three focus areas: Delogu Square, a space with a strong historical identity but still unrealised potential; and Bonapace Square and Dei Caduti Square, cores of public life and service centres. These three focus areas identify a path that, from the main street (Corso Garibaldi), invites the user to enter the historic core of the village, which is often less experienced. The creation of this path can encourage the use of urban spaces and their inclusion in integrated strategies of conservation, restoration, and reactivation. Moreover, stratigraphic analysis on the focus areas allowed the identification of three chronological phases and the tracing of the settlement's evolution over time. It revealed that, even with recent modifications, such as new structures and the raising of the existing ones, the squares maintain their traditional morphology and function as public spaces.

The analysis of the microclimate and outdoor thermal comfort in the present situation on a typical critical summer day highlights a high degree of discomfort, leading to physiological stress caused by the heat. Moreover, even though Osidda is a small village, its compact structure and building materials lead to an urban heat island phenomenon, usually more typical of larger urban settlements. This analysis revealed that, in this case, the primary contributor to thermal discomfort is the solar radiation. Therefore, shading mitigation interventions were selected as the most suitable to mitigate the high levels of thermal stress, and were designed to remain compatible with the historic built environment, with a place-based approach. Enhancing thermal outdoor comfort improves the liveability of public spaces and, consequently, could help foster social reactivation.

The effectiveness of these mitigating interventions was subsequently assessed through a comparison between the PMV thermal comfort index in the current state and that after the mitigation interventions. Results showed that sun sails are much more effective than the green-covered pergolas, although the latter also improved thermal outdoor comfort. Therefore, the geometrical shading using sun sails proved to be the most effective mitigation strategy in this specific urban context. The addition of water sprays led to further minor improvements, but sustainability concerns linked to water consumption make them not recommended in geographical areas affected by drought. While the proposed interventions have proven effective in improving thermal comfort, they should be understood as reversible solutions, designed to minimise physical impact on the historical built environment. Their temporary nature highlights the challenges in identifying long-term design strategies that are both climatically effective and culturally appropriate.

The findings of the present study have highlighted the thermal comfort behaviour of Osidda, a historical village characterised by a compact and stratified urban fabric. The features of the urban morphology significantly contribute to the current adverse thermal conditions. While these same characteristics once functioned effectively under lower historical temperature regimes, they now intensify thermal stress in the context of contemporary climate conditions.

Moreover, improving thermal comfort in specific areas of the urban fabric (seen as potential future hubs of social life) is crucial for enhancing living conditions in historical villages, fragile and marginalised contexts threatened by depopulation. Thus, this specialised yet adaptable methodology may support sustainable urban reactivation and heritage conservation strategies, contributing to the resilience and sustainability of historical settlements in the context of climate change.

Acknowledgments

The models in ENVI-met were developed with the help of Martina Ferraro, a master's student in sustainable building design at the University of Cagliari.

Funding

This project was partially funded by the University of Cagliari, by Sapienza University of Rome, and by Politecnico di Milano through the National PhD Program “Heritage Science.”

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Data are available from the corresponding author upon request.

LLMs Disclosure

LLM tools were used for grammar and style improvement.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

References

- Barriopedro, D., Fischer, E. M., Luterbacher, J., Trigo, R. M., & García-Herrera, R. (2011). The hot summer of 2010: Redrawing the temperature record map of Europe. *Science*, 332(6026), 220–224. <https://doi.org/10.1126/science.1201224>
- Battisti, A. (2017). Revitalization and refurbishment of minor historical centers in the Mediterranean. In A. Sayigh (Ed.), *Mediterranean green buildings & renewable energy* (pp. 235–244). Springer. https://doi.org/10.1007/978-3-319-30746-6_17
- Bianco, D., & Cuboni, F. (Eds.). (2009). *Architetture delle colline e degli altipiani settentrionali: Anglona, Gallura, Goceano, Logudoro, Meilogu, Montacuto, Monte Leone, Sassarese*. Regione Autonoma della Sardegna; Università degli Studi di Cagliari; DEI Tipografia del Genio Civile.
- Brogiolo, G. P. (1988). *Archeologia dell'edilizia storica*. Edizioni New Press.
- Bruse, M., & Fleer, H. (1998). Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling & Software*, 13(3/4), 373–384. [https://doi.org/10.1016/S1364-8152\(98\)00042-5](https://doi.org/10.1016/S1364-8152(98)00042-5)
- Bucchignani, E., Montesarchio, M., Zollo, A. L., & Mercogliano, P. (2016). High-resolution climate simulations with COSMO-CLM over Italy: Performance evaluation and climate projections for the 21st century. *International Journal of Climatology*, 36(2), 735–756. <https://doi.org/10.1002/joc.4379>
- Cherchi, G., & Fiorino, D. R. (2023). Strategie per la conservazione e la rivitalizzazione dei centri storici rurali: Il caso del Borgo Autentico di Osidda in Sardegna (Italia). In P. A. Cruz Franco & A. Rueda Márquez de la Plata (Eds.), *La gestión territorial y el problema de la conservación de los centros históricos y el paisaje* (pp. 166–177). Dykinson.
- Chiri, G. M., Achenza, M., Cani, A., Neves, L., Tendas, L., & Ferrari, S. (2020). The microclimate design process in current African development: The UEM campus in Maputo, Mozambique. *Energies*, 13(9), Article 2316. <https://doi.org/10.3390/en13092316>
- Cirasa, M. (2011). *Recupero degli spazi aperti di relazione nei centri storici minori: Aspetti bioclimatici e innovazione tecnologica*. Gangemi Editore.
- Coccolo, S., Kämpf, J., Scartezzini, J. L., & Pearlmutter, D. (2016). Outdoor human comfort and thermal stress: A comprehensive review on models and standards. *Urban Climate*, 18, 33–57. <https://doi.org/10.1016/j.uclim.2016.08.004>
- Comune di Osidda. (2002). *Piano Particolareggiato del Centro Storico*.
- Comune di Osidda. (2012). *Piano Comunale di Protezione Civile*.
- Comune di Osidda. (2013). *Piano d'Azione per l'Energia Sostenibile*.
- Comune di Osidda. (2015). *Piano Particolareggiato del Centro Matrice*.
- Cortiços, N. D., Mateus, D., Duarte, C. C., & Stefańska, A. (2024). Enhancing outdoor comfort through tensile membrane structures and pavement surfaces: A case study report in Évora, Portugal. *Thermal Science and Engineering Progress*, 53, Article 102740. <https://doi.org/10.1016/j.tsep.2024.102740>
- Cuce, P. M., Cuce, E., & Santamouris, M. (2025). Towards sustainable and climate-resilient cities: Mitigating urban heat islands through green infrastructure. *Sustainability*, 17(3), Article 1303. <https://doi.org/10.3390/su17031303>
- de Zabaryn, G. (1701). Fiscal report. *Quaderni Bolotanesi*, 13, 413–456.
- Deidda, M., Fiorino, D. R., & Vacca, G. (2010). Gestione urbana e programmazione della conservazione: L'apporto dell'ICT. In C. Giannattasio & P. Scarpellini (Eds.), *Proposte per Stampace: Idee per un piano di conservazione del quartiere storico cagliaritano* (pp. 147–152). Gangemi Editore.
- Di Cecilia, L. (1999). *Osidda piccolo sole*. Delta 3.

- Dinić Branković, M., Igić, M., Đekić, J., & Ljubenović, M. (2025). Impact of urban densification on outdoor microclimate and design of sustainable public open space in residential neighborhoods: A study of Niš, Serbia. *Sustainability*, 17(4), Article 1573. <https://doi.org/10.3390/su17041573>
- European Environment Agency. (2012). *Urban adaptation to climate change in Europe: Challenges and opportunities for cities together with supportive national and European policies* (EEA Report No 2/2012).
- Fabbri, K., & Costanzo, V. (2020). Drone-assisted infrared thermography for calibration of outdoor microclimate simulation models. *Sustainable Cities and Society*, 52, Article 101855. <https://doi.org/10.1016/j.scs.2019.101855>
- Ferrari, S., Badas, M. G., Garau, M., Seoni, A., & Querzoli, G. (2017). The air quality in narrow two-dimensional urban canyons with pitched and flat roof buildings. *International Journal of Environment and Pollution*, 62(2/3/4), 347–368. <https://doi.org/10.1504/IJEP.2017.089419>
- Ferrari, S., Santus, A., & Tendas, L. (2024). Validation of a numerical software for the simulation of the pollutant dispersion from traffic in a real case: Some preliminary results. *EPJ Web of Conferences*, 299, Article 01010. <https://doi.org/10.1051/epjconf/202429901010>
- Ferrari, S., & Tendas, L. (2024). Ventilation and pollutant dispersion in a group of courtyard buildings with a diagonal wind. *EPJ Web of Conferences*, 299, Article 01011. <https://doi.org/10.1051/epjconf/202429901011>
- Fiorani, D. (2019). *Il futuro dei centri storici: Digitalizzazione e strategia conservativa*. Edizioni Quasar.
- Fiorino, D. R. (2010). La stratigrafia urbana. In C. Giannattasio & P. Scarpellini (Eds.), *Proposte per Stampace: Idee per un piano di conservazione del quartiere storico cagliaritano* (pp. 69–74). Gangemi Editore.
- Fiorino, D. R., Giannattasio, C., & Vacca, G. (2009). Documenting the intangible: A new approach for preserving immaterial aspects of cultural heritage. In S. Lira, R. Amoêda, C. Pinheiro, J. Pinheiro, & F. Oliveira (Eds.), *Proceedings of the International Conference on Intangible Heritage—Sharing Cultures 2009* (pp. 655–664). Green Lines Institute for Sustainable Development.
- Fiorino, D. R., & Grillo, S. M. (2023). Continuità materica e declinazioni costruttive nel patrimonio storico in granito del nord Sardegna. *MONÈRE. Rivista dei beni culturali e delle istituzioni politiche*, 5(5), 27–50.
- Fischer, E. M., & Schär, C. (2010). Consistent geographical patterns of changes in high-impact European heatwaves. *Nature Geoscience*, 3(6), 398–403. <https://doi.org/10.1038/ngeo866>
- Fu, H., Jiao, Y., Deng, L., & Wang, W. (2025). Dynamic impacts of vegetation growth and urban development on microclimate and building energy consumption. *Sustainable Cities and Society*, 126, Article 106382. <https://doi.org/10.1016/j.scs.2025.106382>
- Garau, M., Badas, M. G., Ferrari, S., Seoni, A., & Querzoli, G. (2019). Air exchange in urban canyons with variable building width: A numerical LES approach. *International Journal of Environment and Pollution*, 65(1/2/3), 103–124. <https://doi.org/10.1504/IJEP.2019.101836>
- Repubblica Italiana. (1993). *Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'articolo 4, comma 4, della legge 9 gennaio 1991, n. 10*.
- Repubblica Italiana. (2017). *Legge 6 ottobre 2017, n. 158: Misure per il sostegno e la valorizzazione dei piccoli comuni, nonché disposizioni per la riqualificazione e il recupero dei centri storici dei medesimi comuni*. Gazzetta Ufficiale della Repubblica Italiana. <https://www.gazzettaufficiale.it/eli/id/2017/11/2/17G00171/sg>
- Repubblica Italiana. (2021). *Piano nazionale di ripresa e resilienza*. <https://www.governo.it/sites/governo.it/files/PNRR.pdf>
- Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., & Thépaut, J.-N. (2023). ERA5 hourly data on single

- levels from 1940 to present [Data set]. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). <https://doi.org/10.24381/cds.adbb2d47>
- International Organization for Standardization. (2005). *ISO 7730: Ergonomics of the thermal environment-analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*.
- Italian National Institute of Statistics. (2025). *Popolazione residente, 2025* [Data set]. <https://demo.istat.it/app/?i=POS&l=it>
- Jon, K. S., Luo, Y., Sin, C. H., Cui, P. Y., Huang, Y. D., & Tokgo, J. (2023). Impacts of wind direction on the ventilation and pollutant dispersion of 3D street canyon with balconies. *Building and Environment*, 230, Article 110034. <https://doi.org/10.1016/j.buildenv.2023.110034>
- Kumar Donthu, E. V. S. K., Shashwat, S., Zingre, K. T., Srinivasan, S., & Wan, M. P. (2024). An investigation of globe temperature in street canyons: A scaled model study implementing cool materials. *Buildings*, 14(10), Article 3054. <https://doi.org/10.3390/buildings14103054>
- Lai, D., Liu, W., Gan, T., Liu, K., & Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of the Total Environment*, 661, 337–353. <https://doi.org/10.1016/j.scitotenv.2019.01.062>
- Manteghi, G., Bin Limit, H., & Remaz, D. (2015). Water bodies an urban microclimate: A review. *Modern Applied Science*, 9(6), 1–12. <https://doi.org/10.5539/mas.v9n6p1>
- Montaldo, N., & Corona, R. (2024). Hydrologic sustainability of a Mediterranean tree-grass ecosystem under climate change. *Journal of Hydrology*, 641, Article 131772. <https://doi.org/10.1016/j.jhydrol.2024.131772>
- Nardecchia, F., Di Bernardino, A., Pagliaro, F., Monti, P., Leuzzi, G., & Gugliermetti, L. (2018). CFD analysis of urban canopy flows employing the V2F model: Impact of different aspect ratios and relative heights. *Advances in Meteorology*, 2018, Article 2189234.
- Ng, E. (Ed.). (2010). *Designing high-density cities for social and environmental sustainability*. Earthscan.
- Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*, 34(6), 563–572.
- Oke, T. R. (1988). Street design and urban canopy layer climate. *Energy and Buildings*, 11, 103–113.
- Oke, T. R. (2002). *Boundary layer climates*. Routledge.
- Olgyay, V. (2013). *Progettare con il clima. Un approccio bioclimatico al regionalismo architettonico*. Franco Muzzio Editore. (Original work published 1962)
- Ormerod, M. G., & Newton, R. A. (2005). Moving beyond accessibility: The principles of universal (inclusive) design as a dimension in nD modelling of the built environment. *Architectural Engineering and Design Management*, 1(2), 103–110. <https://doi.org/10.1080/17452007.2005.9684587>
- Park, K., Jun, C., Baik, J., & Kim, H. J. (2024). Urban canyon design with aspect ratio and street tree placement for enhanced thermal comfort: A comprehensive thermal comfort assessment accounting for gender and age in Seoul, Republic of Korea. *Buildings*, 14(8), Article 2517. <https://doi.org/10.3390/buildings14082517>
- Peng, Z., Chen, Y., Deng, W., Lun, I. Y. F., Jiang, N., Lv, G., & Zhou, T. (2022). An experimental and numerical study of the winter outdoor wind environment in high-rise residential complexes in a coastal city in Northern China. *Buildings*, 12(11), Article 2011. <https://doi.org/10.3390/buildings12112011>
- Puggioni, G., & Bottazzi, G. (2013). *Comuni in estinzione: Gli scenari dello spopolamento in Sardegna—Progetto IDMS-2013*. Regione Autonoma della Sardegna.
- Qin, J., Zhou, X., Sun, C., Leng, H., & Lian, Z. (2013). Influence of green spaces on environmental satisfaction and physiological status of urban residents. *Urban Forestry & Urban Greening*, 12(4), 490–497. <https://doi.org/10.1016/j.ufug.2013.05.005>

- Santamouris, M. (2014). Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, 103, 682–703. <https://doi.org/10.1016/j.solener.2012.07.003>
- Sardinia Autonomous Region. (2007). *Piano Forestale Ambientale Regionale*. https://www.regione.sardegna.it/documenti/1_73_20080129175640.pdf
- Sirigu, S., & Montaldo, N. (2022). Climate change impacts on the water resources and vegetation dynamics of a forested Sardinian basin through a distributed ecohydrological model. *Water*, 14(19), Article 3078. <https://doi.org/10.3390/w14193078>
- Spanedda, F. (Ed.). (2007). *Energia e insediamento. Una ricerca interdisciplinare per l'applicazione di principi di efficienza energetica nei centri storici*. FrancoAngeli.
- Sterl, A., Severijns, C., Dijkstra, H., Hazeleger, W., Van Oldenborgh, G. J., Van Den Broeke, M., Burgers, G., Van Den Hurk, B., Van Leeuwen, P. J., & Van Velthoven, P. (2008). When can we expect extremely high surface temperatures? *Geophysical Research Letters*, 35(14). <https://doi.org/10.1029/2008gl034071>
- Taleghani, M., & Berardi, U. (2018). The effect of pavement characteristics on pedestrians' thermal comfort in Toronto. *Urban Climate*, 24, 449–459. <https://doi.org/10.1016/j.uclim.2017.05.007>
- Ulpiani, G. (2019). Water mist spray for outdoor cooling: A systematic review of technologies, methods and impacts. *Applied Energy*, 254, Article 113647. <https://doi.org/10.1016/j.apenergy.2019.113647>
- Watanabe, S., Nagano, K., Ishii, J., & Horikoshi, T. (2014). Evaluation of outdoor thermal comfort in sunlight, building shade, and pergola shade during summer in a humid subtropical region. *Building and Environment*, 82, 556–565. <https://doi.org/10.1016/j.buildenv.2014.10.002>
- Woolley, H. (2003). *Urban open spaces*. Taylor & Francis.
- Xue, F., Li, X., Ma, J., & Zhang, Z. (2015). Modeling the influence of fountain on urban microclimate. *Building Simulation*, 8, 285–295. <https://doi.org/10.1007/s12273-014-0210-7>
- Yang, J., Wang, Z. H., Kaloush, K. E., & Dylla, H. (2016). Effect of pavement thermal properties on mitigating urban heat islands: A multi-scale modeling case study in Phoenix. *Building and Environment*, 108, 110–121. <https://doi.org/10.1016/j.buildenv.2016.08.021>
- Yin, S., Wang, F., Xiao, Y., & Xue, S. (2022). Comparing cooling efficiency of shading strategies for pedestrian thermal comfort in street canyons of traditional shophouse neighbourhoods in Guangzhou, China. *Urban Climate*, 43, Article 101165. <https://doi.org/10.1016/j.uclim.2022.101165>
- Zhang, B., Li, C. Y., Kikumoto, H., Niu, J., & Tse, T. K. T. (2024). Smart urban windcatcher: Conception of an AI-empowered wind-channeling system for real-time enhancement of urban wind environment. *Building and Environment*, 253, Article 111357. <https://doi.org/10.1016/j.buildenv.2024.111357>
- Zhao, Y., Zhao, K., Zhang, X., Zhang, Y., & Du, Z. (2024). Assessment of combined passive cooling strategies for improving outdoor thermal comfort in a school courtyard. *Building and Environment*, 252, Article 111247. <https://doi.org/10.1016/j.buildenv.2024.111247>
- Zheng, J., Ou, Z., Xiang, Y., Li, J., & Zheng, B. (2025). How can street interface morphology effect pedestrian thermal comfort: A case study of the old town of Changsha, China. *Urban Climate*, 60, Article 102341. <https://doi.org/10.1016/j.uclim.2025.102341>
- Zirottu, G. (2005). *Osidda: Dal passato al futuro*. Grafiche Editoriali Solinas.
- Zuckerman, N., Shiloah, N., & Lensky, I. M. (2025). Quantifying the impact of vertical greenery systems (VGS) on Mediterranean urban microclimate during heat wave events. *Building and Environment*, 267, Article 112151. <https://doi.org/10.1016/j.buildenv.2024.112151>

About the Authors



Giulia Cherchi, architect specialised in conservation, held a research grant at the University of Cagliari and is a PhD student in heritage science at Sapienza University (supervisor: Valeria N. Pracchi). Her research focuses on Sardinian historic villages and improving thermal comfort.



Alessandro Santus, research fellow at the University of Cagliari, specialises in fluid mechanics and urban microclimate design. He uses computational fluid dynamics (CFD) for microclimate and pollutant dispersion modelling, with a recent focus on UAV-based turbulence estimation and safety analysis of building-induced hazardous zones.



Donatella Rita Fiorino, architect and PhD in conservation, is an associate professor at the University of Cagliari. Former officer at MiBACT, she researches conservation and enhancement of historic architecture, with special attention to small villages and marginal areas.



Simone Ferrari, PhD and associate professor at the University of Cagliari, teaches urban microclimate design and fluid mechanics. With over 20 years of experience in turbulence research, he applies experimental and numerical methods to study fluid dynamics in built and natural environments.

Sustainable Futuristic Energy Scenarios for Low-Carbon Industrial Heritage: Green Adaptive Reuse of Karaj Iron Foundry

Farzaneh Gharaati ¹ , Mohammadjavad Mahdavinejad ² , Martin Meyer ³ ,
and Tatsuyoshi Saijo ⁴ 

¹ Department of Architecture, Tarbiat Modares University, Iran

² College of Engineering and Architecture, University of Nizwa, Oman

³ Habitat Unit – Chair of International Urbanism and Design, Technische Universität Berlin, Germany

⁴ Future Design Research Center, Kyoto University of Advanced Science, Japan

Correspondence: Martin Meyer (m.meyer@tu-berlin.de)

Submitted: 25 April 2025 **Accepted:** 31 July 2025 **Published:** 15 September 2025

Issue: This article is part of the issue “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse” edited by Liam James Heaphy (University of Galway) and Philip Crowe (University College Dublin), fully open access at <https://doi.org/10.17645/up.i461>

Abstract

Addressing climate challenges related to carbon emissions, particularly after the Industrial Revolution, is one of our current major global issues. Today, many industrial heritage sites have become abandoned and are known as wastelands. The adaptive reuse of these sites has been recognized as a potential and effective solution to prevent environmental damage while preserving their unique characteristics. Moreover, the conservation of industrial heritage sites requires meticulous planning with a futuristic vision, particularly at the early phases of decision-making. Therefore, this study aimed to examine futuristic sustainable scenarios for industrial heritage sites to reduce their carbon footprint by 2050, with a specific focus on enhancing the energy performance of an industrial heritage site in Iran, the Karaj Iron Foundry. In this study, future scenario-making has been employed as a significant methodology to analyze and investigate future possibilities in energy efficiency and the sustainable reuse of the case study. Three scenarios are presented through the future design and discipline of anticipation frameworks (the FD-DoA method). Each scenario shows alternatives that the site can pursue to mitigate carbon emissions and improve energy efficiency by 2050, which have impacts on the urban scale. The scenarios provide a framework for low-carbon policy development for such valuable industrial heritage sites.

Keywords

carbon footprint; carbon neutrality; designerly decision support system; energy efficiency; futuristic visioning; green adaptive reuse; industrial heritage; low-carbon heritage

1. Introduction

The construction sector is one of the largest energy consumers and a major source of global warming due to greenhouse gases and carbon dioxide production (Abd Elgawad et al., 2025). Adaptive reuse of built environments/buildings reduces carbon dioxide emissions and leads to achieving a low-carbon future (Blagojević & Tufegdžić, 2016). In addition to preserving latent energy (Huang et al., 2025), this approach can also reduce energy costs and control negative environmental impacts through the implementation of energy efficiency ideas and low-carbon strategies (Angrisano et al., 2024; Barone et al., 2024; Gustafsson et al., 2017). Adaptive reuse of industrial heritage (ARIH) sites can play a positive role in improving the urban environment due to their unique features, such as large spaces, strong structures, and location often within the urban context (The International Committee for the Conservation of Industrial Heritage, 2003). However, the problem is that many of these sites are considered urban voids and wastelands due to their semi-abandoned or dilapidated condition. In the adaptive reuse process, due to its impact on urban spaces, it is necessary to coordinate with other urban elements to integrate into the urban context and fulfill the needs of citizens (Trusiani & D'Onofrio, 2024). Furthermore, considering interdisciplinary issues such as climate conditions, urban factors, and the preservation of historical features in the adaptive reuse process is necessary (Abd Elgawad et al., 2025; Blagojević & Tufegdžić, 2016). This makes the decision-making process more complex (Huang et al., 2025; Yung & Chan, 2012). Moreover, given rapid urbanization, adaptive reuse must be carried out with long-term futuristic visioning to ensure sustainability (Boostani & Sadeghiha, 2022; Ouf, 2024), taking into account the opinions and needs of future generations, to improve the urban environment in line with sustainable development (Holtorf & Bolin, 2022).

Recent studies have addressed the energy assessment in the ARIH process. Yang et al. (2025) analyzed the energy consumption of an industrial heritage site before and after reuse in the energy analysis in DesignBuilder software and obtained two scenarios of “enhancements” and “reductions.” Huang et al. (2025) emphasized the full life cycle in ARIH for the assessment of embodied carbon and proposed energy efficiency solutions considering the heritage characteristics. This is because compensating carbon emissions is different for a factory that has never been in operation than for a factory that has been active at the time. Wang et al. (2023) have presented strategies for energy efficiency and carbon reduction that include urban-scale considerations such as the number of floors, road network density, building density, and green space ratio. The results of the study by Guidetti and Ferrara (2023) showed that the latent energy in urban heritage and land use is important in prioritizing interventions for the preservation and reuse of existing buildings in the urban context. Sinou et al. (2023) highlighted strategies in green-blue infrastructure and landscape elements, including ecological corridors or connections between urban elements, which can play an effective role in sustainable ARIH. Pavlović et al. (2022), by examining energy efficiency improvement for an industrial heritage site, emphasized new strategies such as thermal insulation for facades.

Existing research highlights various strategies in ARIH that are often focused on energy efficiency and carbon reduction aspects, and emphasize the connection between the urban environment landscape and people. However, it is necessary to have a comprehensive perspective for a sustainable ARIH. Cultural heritage, as an integral part of the built environment, is significantly linked to identity (Dezfuli et al., 2024) and encompasses valuable human-made features (Goodarzi et al., 2023; Ranjazmay Azari et al., 2023; Shaeri et al., 2022). However, a critical research gap persists; most of these strategies neglect heritage features with a long-term futuristic perspective and lack interdisciplinary integration with futures studies.

In addition, striking a balance between preserving heritage values and applying energy efficiency principles is essential in ARIH. Since heritage belongs to future generations, the perspective of future generations must be taken into account in the decision-making process for ARIH. However, given the lack of future generations' existence, it is necessary to adopt a new approach in which there are some representatives from the current generation, such as Imaginary Future Generations (IFGs).

Therefore, to address these gaps, this study aims to provide energy-efficient solutions for ARIH in Iran, focusing on the Karaj Iron Foundry (KIF), while preserving its historical values and making decisions based on the future generations' needs through the interdisciplinary knowledge of futures studies. This study employs a futuristic visioning approach through expert surveys as IFGs and scenario analysis to balance heritage preservation and energy efficiency. In this study, first, the indicators related to ARIH were identified with a comprehensive perspective. Then, the importance of the indicators for ARIH in Iran was assessed through a questionnaire completed by experts in the form of IFGs. Next, experts presented energy efficiency solutions based on the priorities of the indicators, and in sustainability dimensions, with a futuristic perspective in what we called a "future design" workshop. The case study, KIF, needs reconstruction and revitalization due to its current unfavorable condition and serious threats of destruction. Also, due to the rapid urban development and population growth of Karaj city in recent years, this area will face challenges in the future. Finally, the differences, similarities, and impacts of the solutions were examined through a tree diagram analysis (TDA) by analyzing the scenarios. This study provides practical strategies for policymakers, decision-makers, and government institutions for adaptive reuse of the KIF, considering future conditions of Iran and preserving heritage values. The future design and discipline of anticipation frameworks (the FD-DoA method) provides a useful path for decision-making for other industrial heritage sites.

2. Energy Efficiency in Iran

Iran is one of the top ten carbon dioxide-producing countries in the world, and its energy consumption is three times the global average (Hosseini et al., 2019; Iran Renewable Energy Association, 2022). Buildings, as the largest energy consumers in Iran, play a significant role in this condition, and most of the country's energy is supplied by fossil fuels. Although the trend of oil production and consumption has fluctuated in recent years (International Energy Agency, 2025; World Bank, 2025), due to Iran's complex energy relations and the oil trade restrictions, dependence on these sources must be reduced and alternatives found (Shikh Mohammadi & Hashemi, 2024). The importance of this issue is so great that a major part of Iran is covered by warm and arid climate zones, and this amount is expected to reach more than 90% by 2050 (Kiani & Kamangar, 2022). Also, increasing carbon dioxide emissions by 2100 will increase the average temperature of the country by 1.5–4.5°C, which could have significant effects on energy demand (Ghazi et al., 2025). In this regard, one of the domestic measures to control this issue is the document by the Research Center of the Islamic Consultative Assembly (RCICA) in 2023. While this document presents a set of solutions (e.g., implementing energy optimization plans, diversifying the energy portfolio by developing renewable energies, creating sustainable job opportunities to address environmental problems, developing a circular economy in the country, and promoting interactions with neighboring countries to strengthen the technology transfer mechanism), they are just proposals, not requirements. Moreover, the enforcement mechanisms are weak and need careful planning to deal with the environmental crises in Iran. Although numerous abandoned industrial heritage sites exist in Iran (Gharaati et al., 2023) and represent untapped potential for reducing urban greenhouse gas emissions, such strategies remain absent from current policy proposals.

3. The Industrial Heritage of the KIF

3.1. Historical Context

During the Pahlavi era (1925–1978), an industrial revolution occurred in Iran that was accompanied by the cooperation of foreign engineers and led to the implementation of many industrial infrastructures. This experience played a significant role in Iran's self-sufficiency in the production of industrial goods. One of these major projects was the KIF, which started in 1936 with the collaboration of German experts. The 18-hectare factory was designed by the German consortium Demag-Krupp and architects Hans G. Meyer and Martin Hoffmann in the modern Iranian-Pahlavi style. It was initially intended to produce 100,000 tons of steel per year, but the construction was halted due to the World War II (Figure 1). Today, the KIF is a historical monument that reminds the aspirations of Iran's industrial society, as well as reflects the impact of World War II on the country (Ghazi Moghadam & Madahi, 2014; Lajvardi, 1985).



Figure 1. The KIF during operation. Source: Bildarchiv der Philipp Holzmann AG (1939–1940).

3.2. Current Use and Condition

Today, the Alborz Mining Industry and the Karaj Municipality are known as the owners of the KIF. It is estimated that around eight years of its useful life remain (Sotodeh & Ghobadian, 2022). The Iran Steel Trading Services Company has allocated a part of the land to the depot and scrap metal at present. Another part has been leased to the organizations for truckers' parking and a CNG fuel station. One of the most important features of this industrial heritage site is its location in the urban context and its proximity to a variety of uses (Figure 2).

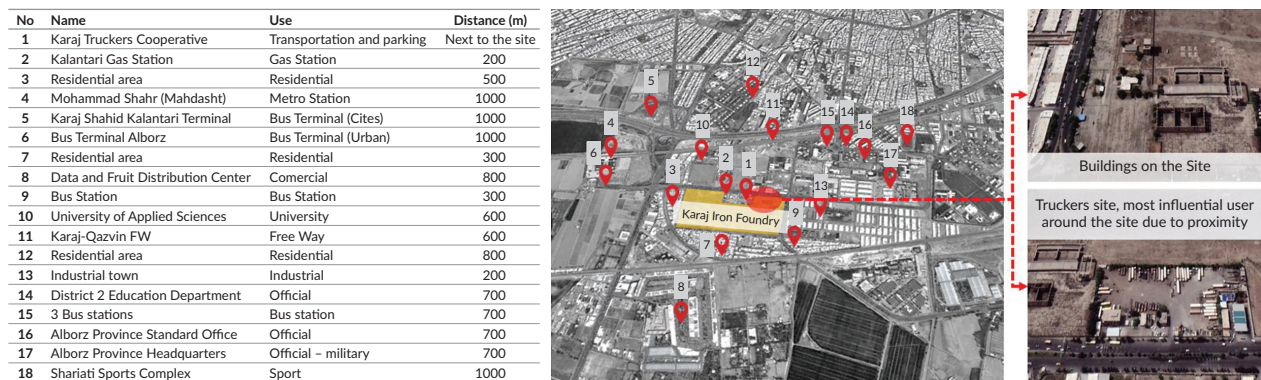


Figure 2. Around the KIF, up to an almost 1 km radius. Images collected using Google Maps.

3.3. Site Visit Observations

According to the visit conducted by the first and third authors in 2022, the overall condition of the site is very critical, and since this site has never been used, it is only familiar to a group of people. Therefore, it needs to be addressed as soon as possible. The industrial area can be divided into two parts: (a) an eastern-western area and (b) non-industrial spaces, which include houses for engineers. The structures in the industrial part are in the skeleton stage, and some of them do not have roofs. They have been designed in the modern Iranian Pahlavi style, and show a unique fusion of modern and traditional architectural elements. Although most of the buildings in this area are structurally stable, they are in a deteriorating condition and need serious attention. Furthermore, coatings, exterior layers, and interior spaces are at risk of destruction due to the lack of cover in the openings. The site's physical condition is almost stable, though material efficiency and sustainability are compromised due to decay. Moreover, it seems it is not very aesthetically pleasing to local people. In terms of urbanity, it has no relation to other surrounding areas, but it has the potential for reuse.

Based on observations during site visits, in the non-industrial space, there are several houses near the site that were designed for German engineers at the time. There is also a building near the site that was a guesthouse for other engineers, now converted into the Harmonic Centre.

In the western part of the industrial area, the constructions on site are (see Figure 3): the office brick building with two floors, built in the German architectural style, and in reasonably good structural condition—the interior space here has a flat roof covered with beams and brick frames and embossed semi-crescent arches decorate the exterior (3a); a semi-finished brick structure with no interior space (3b); semi-finished concrete structures, in which one of the buildings has exposed rebars—a concrete placer material transfer channel of about 200 meters in length and more than 2 meters in width starts from the main hall and the possible location of the kilns and extends to the back of the office building (3c); a six-story building, the use of which was for refrigeration and storage nearby (3d); an office building and a large pond on the west side (3e, 3f); structures in the initial stages and foundation (3g). In the eastern part of the industrial area, there is a concrete building about 10 meters high, built on two levels, with a railway crossing on 4 meters under the ground (Figures 3h and 3i).

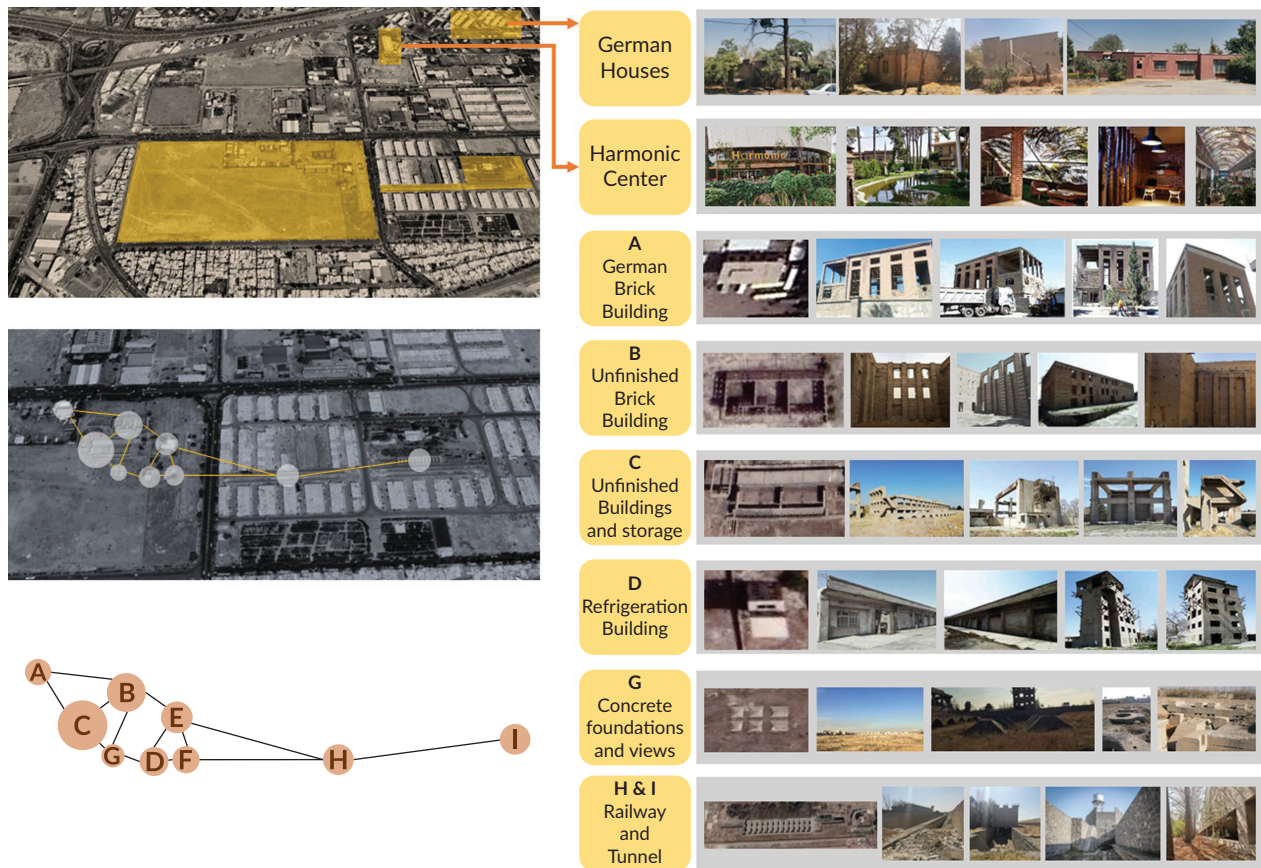


Figure 3. Current situation of the remaining buildings and structures of the KIF. Source: Location map was collected using Google Maps and photos were taken by the authors.

3.4. Heritage Significance

The architectural style is a combination of modern and traditional Iranian aesthetics, which reflects the aspirations and identity of the Pahlavi era. While a part of the land serves industrial purposes, the larger section remains abandoned. There are several threats, such as the absence of vegetation, potential vandalism by truck drivers, and the lack of protective policies. Moreover, the pure volumes of the buildings, rectangular geometry, and low-rise core are the prominent architectural features of the buildings. The consecutive windows on the walls play an effective role in lighting the space. Wooden molds on the concrete from under the roof add a touch of modern decoration. Semi-finished brick and concrete structures, along with a six-story building, portray the technical prowess of the time. The large spaces and robust structures of the KIF make it ideal for adaptive reuse. However, the future climate condition of Iran (Section 2) and the current situation of the site need innovative approaches to balance heritage preservation and carbon reduction goals. Although studies on the KIF emphasize the urgent need for its conservation (Sotodeh & Ghobadian, 2022), Iran lacks specific legal frameworks for conserving industrial heritage sites (Gharaati et al., 2023). Therefore, this study addresses these gaps through a futures' study methodology to develop future scenarios considering both historical values and energy efficiency goals.

4. The Karaj City: Current Conditions and Future Challenges

Considering the location of the KIF in Karaj city, it is essential to examine the sustainability dimensions of this region, including climate and urban conditions. Karaj (the capital of Alborz province), the fourth largest city in Iran, is located 36 kilometers from Tehran (the capital of Iran) and under the influence of the Alborz highlands, the Chalus Valley, and the Karaj River, has a cooler and wetter climate than Tehran. This city sometimes experiences heavy rainfall and flash floods during the summer. The absolute minimum and maximum temperatures are -20°C and $+42^{\circ}\text{C}$, respectively, and the annual average temperature is 14.1°C . The prevailing wind in Karaj is northwesterly, and its average speed is 3.4 meters per second.

Air pollution and inversion are among the most important environmental challenges in Karaj, which occur due to the expansion of the city, heavy vehicle traffic, and the presence of factories and industrial estates (Boostani & Sadeghiha, 2022). Air pollution in this city is so severe that in 2021, Karaj experienced 94 days of unhealthy air due to high amount of the matter smaller than 2.5 microns (PM_{2.5}; Shahbeik et al., 2022). Another environmental challenge is its high vulnerability to frequent earthquakes (Aslani et al., 2019).

Karaj city recorded the highest population growth rate among Iranian cities in 2023, at 4.7%. This issue was so significant that until 2010, Karaj was part of Tehran province. However, due to rapid urban growth and population increase, it was introduced as the capital of Alborz province. This population increase, which was caused by widespread migration, has become a significant issue due to its proximity to Tehran and lack of comprehensive urban planning (Shakarami et al., 2021). In the past, Karaj city was beautiful with green urban gardens due to its favorable climate and water resources. However, today, these areas have been mainly converted into residential areas and roads due to urbanization, human construction, and extensive migration. Recent studies show that there is a significant decrease in the area of gardens and vegetation in Karaj (approximately 10 million square meters, from $56.689.539\text{ m}^2$ to $45.876.904\text{ m}^2$, from 2001 to 2021; see Ghorbani & Sajadzadeh, 2024). Furthermore, the environmental quality of Karaj has notably decreased. The Remote Sensing Ecological Index reflected a decrease of 0.34 (from 0.59 to 0.25, from 2010 to 2022; this index typically ranges from 0 to 1, with higher values indicating better ecological quality; see Naseri et al., 2025). As pollution and climate change continue to increase, environmental conditions and quality of life in Karaj will face more challenges by 2050 (Figure 4). These urban pressures directly impact the adaptive reuse potential of the KIF. For example, controlling air pollution requires environmentally friendly and low-carbon adaptive reuse strategies. Moreover, population growth could pose a threat to KIF by increasing



Figure 4. The changing face of green spaces and urban sprawl in Karaj city, the KIF area: March 2004 (left) and March 2024 (right). Images collected using Google Earth.

demand for housing development. Therefore, the 18-hectare KIF site has the potential to address these pressures through green rehabilitation.

5. Anticipating Urban Futures

Cities are complex networks of elements and are known to be highly sensitive to various factors in sustainability dimensions (Huang et al., 2025). This complexity makes it challenging to accurately anticipate their future. However, forecasting methods can anticipate future directions, taking into account uncertainties while embracing the different dimensions of sustainability (Ouf, 2024).

Urban futures can be classified as possible, plausible, and probable futures. Possible futures are formed based on past trends, probable futures mostly rely on scientific predictions, and plausible futures are shaped based on the opinions of city leaders and people (Gall et al., 2022; Mahdavinejad et al., 2025). On the other hand, due to the nature of heritage and its transmission to future generations, “time depth” becomes important since heritage can act as a bridge to connect the past to the future (Grazuleviciute-Vileniske & Zmejauskaite, 2025). Hence, it is necessary to make decisions for the adaptive reuse of the KIF by utilizing the interdisciplinary knowledge of futures studies. The FD-DoA methods were used to advance this goal.

5.1. Future Design

The decisions of the current generations will have a significant impact on the future generations’ lives. However, future generations are not present in today’s decision-making process and cannot express their opinions. Therefore, there is a need to adopt a method in which the current generation acts as representatives of future generations and participates in decision-making. The “future design” method seeks to incorporate the perspectives of future generations into the current decision-making process (Saijo, 2019) while defining the term “futurability.” This method was implemented in a workshop series structured around three designs: past design, present design, and future design. The purpose of the future design method is to help current generations imagine themselves as IFGs and participate in the group decision-making of current generations (Kamijo et al., 2017; Saijo, 2023). The main mechanism of the future design method is that participants travel to the future with a time machine at the same age and make decisions about issues based on the condition of that future. When they travel into the future, they no longer pay attention to short-term and superficial issues, and long-term issues attract their attention with a deeper perspective (Hara et al., 2019). Then, the person offers appropriate strategies for *their* present (Saijo, 2025). This approach raises awareness of the current generations about their responsibilities toward future generations (Hara et al., 2021; Saijo, 2024). Since adaptive reuse is a process that requires careful attention to various aspects, such as legal restrictions related to heritage preservation, the feasibility of proposed solutions, and the ability to address the challenges, holding workshops with experts is necessary (Arfa et al., 2024). Therefore, in this research project, due to the complexities of adaptive reuse, the future design workshop was held with experts. Conducting all three workshops helps to assess shifts in participants’ perspectives. However, the future design workshop, as the core session of the future design method, activates the futurability. Therefore, according to the aim of this study—which is to develop future scenarios and strategies—only the future design workshop was conducted.

5.2. The Discipline of Anticipation

Engaging in anticipation studies requires a meticulous approach that begins with defining the knowledge area and selecting appropriate methodologies. To overcome the challenges in evaluating anticipations, it is useful to adopt the concept of futures literacy (FL), which is similar to acquiring a new language skill for effectively navigating the future (Holtorf, 2022; Miller, 2018). FL encompasses the understanding of “what to know,” “when to know,” and “why it is important to know” (Miller et al., 2013).

Anticipation aims to implement results derived from forecasting and foresight into decision-making and actions. This is evident in various temporal patterns, from micro anticipations in perception to broader forms of social anticipation spanning seconds to decades (Poli, 2017). The first phase of anticipation studies raises critical questions about participant selection, methods of invitation, and the location of the process. One of the challenges of FL is to collectively change participants’ perceptions to form a shared understanding of the future, and it often requires collaborative work in small groups. The selection of participants and locations depends on factors such as the group members, the topic, the time available, and the context (Miller, 2018). The integration of the discipline of anticipation (DoA) in this research is explained in more detail in the following section.

6. Research Method

To create a balanced vision between preserving heritage values and energy efficiency in ARIH, by referring to the international charters for the conservation of cultural and industrial heritage (including Nizhny Tagil, Dublin, Taipei, and Venice; see Gharaati et al., 2023) and green building certifications (including DGNB, LEED, CASBEE, BREAM, and GREEN-star), 47 indicators were divided into seven categories (see Table 1).

Then, using the perspective of the IFGs and examining the anticipated futures for Iran as well as scientific studies on energy efficiency, an initial assessment was conducted based on the identified indicators. At this stage, 23 experts were selected with doctoral degrees in the fields of architecture (6), civil engineering (5), urban planning (5), archaeology (4), and environment (3). The number of experts was balanced to ensure a comprehensive perspective and minimize potential bias, inspired by DoA. They were selected based on previous knowledge by the authoring team to ensure a minimum of five years of experience and peer-reviewed publications in their fields, with various geographic representations across Iran. They were asked to assess the importance of the indicators from the perspective of the IFGs, considering the future of Iran’s energy for ARIH, through a 7-point Likert scale questionnaire. The results of this stage and the weight of the indicators were also useful for assessing other Iranian industrial heritage at level 1 (De Santoli, 2015). The future design mechanism (Sec 5.1) was explained to the participants via a 7-minute movie.

Then, for the presentation of energy efficiency scenarios for the KIF, inspired by DoA among the 23 experts, based on their close field of study with adaptive reuse of heritage, nine of them met the criteria and were invited. The online future design workshop was held on the Zoom platform since the experts were from different geographical locations in Iran. The authors acknowledged that the virtual FD workshop might have limited the depth of creative ideas compared to in-person future design workshops, but they tried to mitigate this limitation by creating a friendly environment for discussion during the online meeting. Finally,

Table 1. The indicators and categories.

Category	Abbreviation	Indicators
History	HIST	1—Integrity, 2—Sense of place, 3—Homogenous use, 4—Reversible physical intervention, 5—Public participation, 6—Use of educational facilities, 7—Creativity
Environment	ENV	1—Building life cycle assessment, 2—Local environmental impact, 3—Sustainable resource extraction, 4—Potable water demand, 5—Land use, 6—Biodiversity
Economy	ECO	1—Life cycle cost, 2—Flexibility and adaptability, 3—Commercial viability
Social-Cultural	SCO	1—Thermal comfort, 2—Indoor air quality, 3—Acoustic comfort, 4—Visual comfort, 5—User control, 6—Quality of indoor and outdoor space, 7—Safety and security, 8—Design for all, 9—Future generation perspective
Process	PRO	1—Comprehensive project brief, 2—Sustainability aspect in tender phase, 3—Documentation for sustainable management, 4—Urban planning and design process, 5—Construction process, 6—Quality assurance of construction, 7—Systematic commissioning, 8—User communication, 9—Facility management planning, 10—National legal policies
Technology	TEC	1—Fire safety, 2—Insulation layers, 3—Quality of building envelope, 4—Use of technology, 5—Ease of cleaning, 6—Ease of recovery and recycling, 7—Immission control, 8—Mobility infrastructure
Site	SITE	1—Natural disaster and risk management, 2—Influence of district, 3—Transport access, 4—Access to amenities

five experts participated in this meeting (one heritage specialist, one civil engineer, two architects, and one urban planner). The future design workshop followed Saijo's (2025) protocol and was held as follows:

1. A week before the future design workshop session, information related to the energy efficiency of Iran, the industrial heritage of Iran, the KIF, the Karaj city's conditions, and the results of the questionnaire were sent to participants in the form of a pamphlet (see also Nishimura et al., 2020).
2. On the day of the FD workshop, before the discussion session, through the future design method, participants were given the task of imagining themselves in the future at the same age, traveling to the future in 2050 by a time machine, and present energy efficiency scenarios for the KIF (see Nakagawa et al., 2024).
3. During a two-hour discussion, three scenarios were presented.

In the final stage, the scenarios were analyzed using TDA by the authors, and their similarities and differences were analyzed. The TDA was used for its capacity for visual mapping, and provides a clear visual representation of the similarities and differences in each scenario. As a result, a general energy efficiency approach for the KIF was proposed with a futuristic perspective up to 2050. In addition to preserving heritage values, this approach incorporates time-based energy efficiency strategies aligned with future predictions (Figure 5).

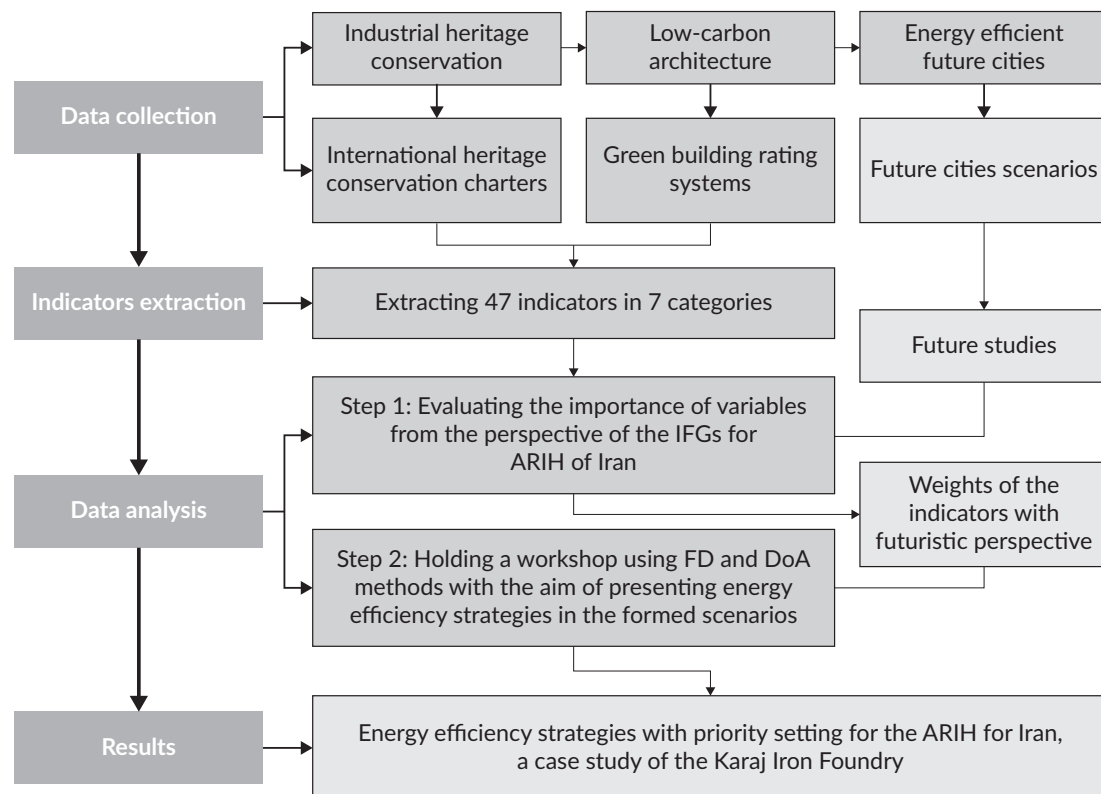


Figure 5. The structure of the research.

7. Results

7.1. 1st Step: Determining the Weight of Indicators

In this step, a fuzzy computing environment for data analysis was necessary due to the high uncertainty. The fuzzy Shannon entropy, as one of the most powerful MCDM methods, was selected for its capacity to handle this linguistic uncertainty and objectively weight indicators without requiring a priori assumptions. Therefore, the data was analyzed using the Shannon entropy method in a fuzzy environment (Monghasemi et al., 2015). Hosseinzadeh Lotfi and Fallahnejad (2010) proposed an approach based on Shannon's entropy using interval data such as the α -cut (Table 2). According to previous studies, the most commonly used alpha value is 0.5; therefore, this value was applied in the calculations.

Table 2. Linguistic values and their alpha interval values.

Linguistic value	Alpha interval value
Very low	[0.060, 0.186]
low	[0.186, 0.311]
Somewhat Low	[0.311, 0.437]
Neutral	[0.437, 0.562]
Somewhat High	[0.562, 0.686]
High	[0.686, 0.811]
Very High	[0.811, 0.935]

After the analyses, the weights of the indicators were obtained as shown in Figure 6 and Table 3. The top 10 indicators with the highest weight are respectively: PRO7 (0.0276), PRO2 (0.0255), PRO3 (0.0244), PRO4 (0.0244), ENV3 (0.0241), PRO1(0.02388), SITE1 (0.02385), ENV4 (0.02339), ENV1 (0.0232), TEC4 (0.0229). Also, the order of importance of the categories is as follows: PRO (0.224), SOC (0.187), TEC (0.162), HIST (0.146), ENV (0.132), SITE (0.082), ECO (0.064).

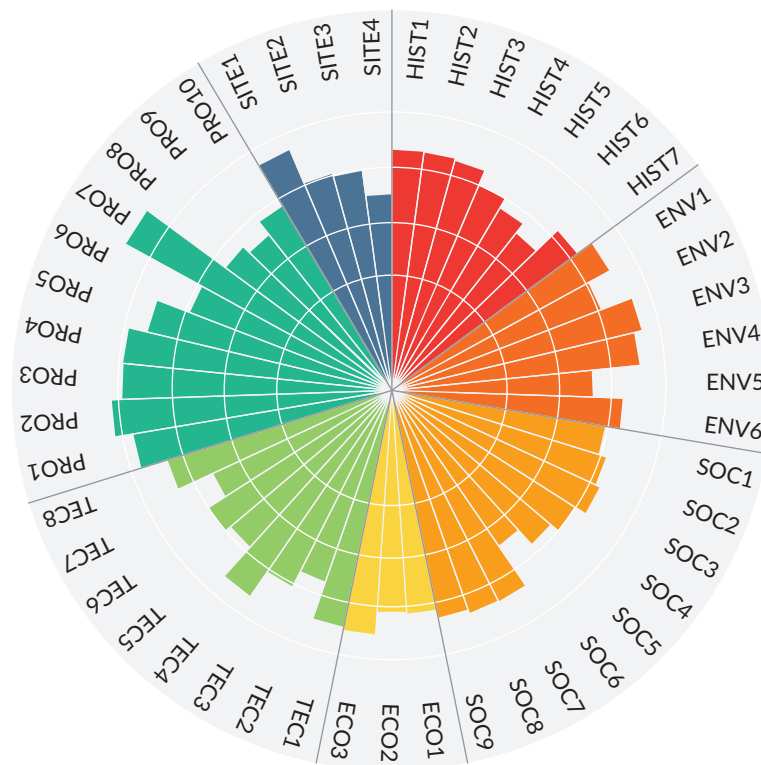


Figure 6. Prioritization of indicators with their categories.

The dominance of “process” (PRO, 22.4%) reflects experts’ prioritization of adaptive reuse implementation indicators over the other categories. Furthermore, the mid-range weighting of the HIST (14.7%) shows that IFGs consider a more balanced preservation needs with adaptive reuse requirements, in contrast to approaches focused solely on preservation. The maximum weighted indicator (PRO7) shows the IFGs’ prioritization in futurability, and phased planning ensures reversible interventions and the protection of heritage values by taking into account uncertainties and temporal changes. These weighted indicators shaped the future design workshop’s scenario-making, as discussed in the next section.

7.2. 2nd Step: Holding the Future Design Workshop

Based on futures studies, the major category of the three scenarios for the KIF was developed by the authors: probable, possible, and plausible futures. The participants were asked to discuss the details, such as hypotheses, uncertainties, solutions, challenges, and impacts for each scenario collectively as one group. The solutions were proposed based on the weighted indicators in the previous step. In all scenarios, the final use of the KIF was envisioned as a mixed-use complex.

Table 3. Weights of the indicators and their categories based on the questionnaire analysis.

Economy (0.0641)	Environment (0.1326)	History (0.1467)	Process (0.2242)	Social-Cultural (0.1870)	Technical (0.1625)	Site (0.0825)
ECO1 0.02083	ENV1 0.02324	HIST1 0.02213	PRO1 0.02388	SOC1 0.02052	TEC1 0.02224	SITE1 0.02385
ECO2 0.0206	ENV2 0.02116	HIST2 0.02208	PRO2 0.02556	SOC2 0.02121	TEC2 0.01867	SITE2 0.02053
ECO3 0.02268	ENV3 0.02410	HIST3 0.02194	PRO3 0.02445	SOC3 0.02161	TEC3 0.02028	SITE3 0.02025
	ENV4 0.02339	HIST4 0.02062	PRO4 0.02445	SOC4 0.02076	TEC4 0.02291	SITE4 0.01789
	ENV5 0.01900	HIST5 0.01969	PRO5 0.02266	SOC5 0.01960	TEC5 0.01926	
	ENV6 0.02172	HIST6 0.01873	PRO6 0.01957	SOC6 0.01764	TEC6 0.01989	
		HIST7 0.02149	PRO7 0.02762	SOC7 0.02211	TEC7 0.01791	
			PRO8 0.01874	SOC8 0.02199	TEC8 0.02141	
			PRO9 0.01792	SOC9 0.02159		
			PRO10 0.01938			

7.2.1. Scenario 1: Sustainable Progress (Plausible Future)

In this scenario, it is assumed that by 2050, Iran has succeeded in developing sustainable energy policies, reducing its dependence on fossil fuels, and replacing them with renewable energy sources. Economically, the country has transitioned towards sustainability, and there is effective coordination between the Cultural Heritage Organization and the owner. The government has provided sufficient financial resources to invest in the rehabilitation and adaptive reuse of the KIF. On the other hand, the population of Karaj, which was a major challenge in 2025, has been managed sustainably, and the urban infrastructure has been improved for the rehabilitation of the KIF.

The uncertainties of this scenario include the quality of implementation and innovations. Public acceptance is also another uncertainty that depends on the support of local communities and officials for the ARIH and the level of public acceptance after the adaptive reuse.

Effective solutions in this scenario are based on the success of Iran's sustainable energy policies in 2050. Therefore, a step-by-step systematic implementation with phased perspectives (every ten years, until 2030, 2040, and 2050) and detailed planning for the exploitation of all buildings was proposed (PRO7). The management plan is provided up to 2030, the urban issues, connections through roadways or bicycle paths have been designed, and green spaces and open areas have been implemented up to 2040. Furthermore, the energy-efficient and smart technologies have been implemented up to 2050. Office buildings located in the truckers' area are prioritized due to their good physical conditions (TEC4). In this

scenario, on-site energy generation and its use for other local users are also possible, provided that the heritage identity of the existing buildings is preserved (ENV1). In the case of implementing a double-skin brick facade, interventions should not affect the heritage values of the facade. Since the skeletal structures are roofless, the use of natural light or skylights will be useful (TEC4). Moreover, due to Iran's progress in the field of production, the use of sustainable and recyclable materials such as recycled bricks is recommended, along with compliance with health and environmental standards at all stages (ENV3). Also, in open spaces and on an urban scale, due to the coordination of decision-making bodies, to interact with other urban elements after the adaptive reuse of KIF, medicinal and indigenous plants can be used for greening the space (PRO4). In addition, due to the development of sustainable energy systems, life cycle analysis will be useful with the aim of reducing environmental impacts (ENV1). For the use of passive energy, according to the "compact cities," the use of underground spaces that lead to maximum use of urban land is suggested. In Iranian vernacular architecture, a *Shavadan* (or *Shadan*) is an underground and naturally cool space used in hot and humid climates to escape the heat. These spaces were typically constructed with stone and brick that provided thermal comfort for occupants through insulating properties and protection from direct sunlight. A similar effect for the KIF can be attained by connecting it to the adjacent Mohammad Shahr metro station through underground corridors. Commercial, cultural, and educational activities can take place in this corridor. Also, due to the government's financial support for the adaptive reuse of KIF, new and additional structures can be added to the space in a precise and planned manner. Due to the coordination of government agencies, it is also possible to plan for public participation in the adaptive reuse process through surveys and discovering their local needs (PRO1).

One of the most important challenges is the complexity of planning and implementing solutions for the adaptive reuse of the KIF. No matter how good the economic conditions in Iran are, the decision to implement energy efficiency solutions in this process still complicates the situation. The combination of new technologies and sustainable energy efficiency solutions must also be coordinated with the conservation of heritage and identity. The technical implementation of innovative ideas requires high technical knowledge and specialized teams. The location of photovoltaic cells in this scenario was discussed by experts. On a macro-scale, if photovoltaic cells are to be installed on the ground, their impact on vegetation should not be overlooked. Also, the balance in land use between vegetation and photovoltaic cells should be considered, as this affects local biodiversity. On a micro scale, photovoltaic cells can affect the color, geometry, reflection, and elevation of the ground. Furthermore, if the installation is on the roof of buildings, the proportionality of its geometry and the preservation of the historical identity should be prioritized.

As a result of this scenario, the adaptive reuse of the KIF can serve as a model for reducing and properly managing energy consumption and carbon emissions for other industrial heritage sites. Also, if the KIF could draw public attention after adaptive reuse, this project can help increase public trust in the government and cultural institutions.

7.2.2. Scenario 2: Survival and Adaptation (Possible Future)

In this scenario, it is assumed that by 2050, climate change and economic pressures have continued to affect the country, but the government has been able to provide limited financial resources for the restoration and sustainable reuse of the KIF. Karaj's urban population has continued to grow, but it has not posed a significant threat to the city or the restoration of the KIF. The Iranian government's energy efficiency policies have generally been implemented gradually, but with limited effects.

The uncertainty in this scenario is the limited resources. Besides, the extent of government policies to support the sustainable reuse of the KIF and the availability of a skilled and experienced workforce to implement these project goals are unknown. Moreover, although public transportation can play a positive role in urban energy efficiency, a precise decision cannot be made for KIF due to the limited energy efficiency policies.

In this scenario, assuming that energy efficiency policies in Iran have been generally established, solutions extend beyond energy efficiency and move towards low-carbon strategies. Systematic implementation is combined with the concept of monitoring, which occurs every five years (PRO7). Moreover, at each stage of monitoring, testing, and evaluation of progress and changes should be carried out, and planning must be readjusted based on the results (PRO1). Regarding sustainability, it is necessary to examine the past, present, and future of the KIF in sustainability dimensions. In particular, due to the inactivity of the KIF in the past, this site is considered relatively a low carbon producer and has caused less environmental damage than other industrial sites that produced lots of carbon during their operation. However, due to its inactivity in the past, it did not contribute to the growth of the economy of Iran at that time and did not employ people for iron smelting (PRO2). In addition, due to its inactivity in the past, people only remember a few stories of the past. These issues became more serious in the past dimensions of this scenario to enhance the sense of belonging (ENV1). Regarding open spaces, Iranian garden design principles are considered a solution to improve air quality and increase energy efficiency (TEC4). In the past, Karaj was covered with gardens, but urbanization has led to their disappearance. It is time to attract people to KIF through collective memory. Iranian gardens do not require much care and can improve the microclimate by creating shade, pleasant air in the open air, and natural ventilation because of the use of special geometries, precise sizes and proportions, and native plants (Afsahhosseini, 2024). In addition, due to the limited water resources in this scenario, rainwater and greywater recycling systems can be used to reduce water consumption for irrigation (ENV4). Similarly, due to limited financial resources, it is necessary to propose energy efficiency solutions through BIM for optimal management and operation of buildings (PRO3). Therefore, passive energy solutions combined with active ones are proposed (TEC4). The orientation of the buildings on the KIF is East-West and has the potential to use natural lighting. Due to the prevailing northwesterly winds from the Alborz Mountains and the orientation of each building, which has the largest influence on energy demand, the buildings have good potential for natural ventilation. Also, the use of natural light in this scenario should be without heat transfer. Due to resource limitations, it is necessary to prevent the construction waste at the site during the adaptive reuse process (ENV1).

Similar to the first scenario, the complexity of adaptive reuse, while considering the preservation of heritage values, remains one of the most important challenges. However, due to resource limitations and the lack of specialized experts, obtaining funding for this project and justifying it to government agencies for possible return on investment is challenging. In addition, short-term monitoring for five years requires careful planning, advanced monitoring tools, and coordination between stakeholders.

The impact of this scenario, which results from the combination of passive and active solutions, the use of green space, and the Persian garden, is the potential for a reduction in energy consumption; however, its effectiveness depends on resource and technological constraints. Additionally, the adaptive reuse of the KIF, in line with sustainable solutions and green space design, can help create a relaxing and pleasant environment for people and improve the quality of life and health.

7.2.3. Scenario 3: Failure and Inaction (Probable Future)

In this scenario, it is assumed that, by 2050, the Iranian economy will have remained in recession, and the government will have had very limited financial resources for revitalizing and adapting the reuse of the KIF. In addition, climate threats such as global warming, air pollution, earthquake management, etc., have remained unresolved in Karaj, intensifying their destructive effects. The population of Karaj has continued to increase due to migration without proper management. On the other hand, sustainable energy management policies and programs for the adaptive reuse of the KIF in Karaj have not been implemented effectively due to the lack of sustainable energy management.

The uncertainties of this scenario are based on resource shortages, lack of effective management, and worsening economic conditions. The extent of the deterioration of Iran's economic situation and inflation is unknown. It is also unclear how the government will approach the adaptive reuse of the KIF in the event of an economic downturn. On the other hand, the cooperation between different government departments and the prioritizing of adapting reuse of the KIF in those economic conditions is under question. Also, the physical condition of the existing buildings may have deteriorated to such an extent that reconstruction is no longer possible, and the adaptive reuse of the KIF is not economically justified.

Given that energy efficiency policies in Iran cannot be properly implemented in this scenario, solutions often tend to focus on low-carbon strategies. Due to the increasing number of uncertainty items, systematic planning and implementation are very difficult, and among the sustainability dimensions, economic and social aspects play a more prominent role in the process of adaptive reuse. Also, in this scenario, it is necessary to form an independent design committee to preserve and restore the existing buildings of the KIF (PRO7). Moreover, due to the increased role of people in decision-making processes and the impact of user behavior, their activities' impact on energy efficiency solutions after reuse should be predicted in advance (PRO2). In addition, to incorporate people's opinions and participation in decision-making, it is first necessary to raise awareness about historical interpretation. For example, the aesthetic interpretation of a heritage site may differ from the perspective of people about a rough concrete building. Citizens deal with urban issues every day, and based on their real experiences, they know where the obstacles are. In addition, due to the increase in climate risks, natural disasters, and fires, the KIF needs to be secured against these threats (SITE1). Moreover, the energy systems of the buildings need to be removed from private control and changed to an integrated manner. In this scenario, participants were uncertain about the use of passive solutions, but emphasized the greening of open spaces and using Iranian vernacular architecture to mitigate climate impacts (PRO4). Given the prominent role of economic aspects in this scenario, it is necessary to plan for different users with different needs to enhance the return on investment and economic justification. Therefore, the site can be used continuously over time to maintain the economic viability of the project (ECO3).

The challenges of this scenario include the lack of justification by the executive bodies for the return on the investment. In addition, air pollution and negative climate effects, such as humidity and heat, can accelerate the deterioration of structures. In addition, the uncontrolled population growth in Karaj has placed significant pressure on urban infrastructure, and the 18-hectare KIF site may be considered for urgent urban needs, such as housing.

If this project is successful in this scenario, despite limited resources, it can be a model for other similar projects in the country. Additionally, raising public awareness about the historical value of the site, attracting their participation, and incorporating their opinions and suggestions can strengthen the sense of belonging to the site and prevent further deterioration of the energy efficiency situation.

8. Discussion

This research aimed to provide low-carbon and energy solutions with a futuristic perspective for an ARIH. The case study was the KIF in Iran. The scenarios were made through the FD-DoA methods, synergistically. Future design methods created intergenerationally equitable scenarios through IFG role-playing, while DoA provided a systematic structure through futures studies protocols. The descriptive framework, including scenarios, uncertainties, challenges, and the impact of strategies, was inspired by DoA, and the imagination process of the future scenarios and activating the participants' futurability was shaped through the future design methodology, ensuring creative balance for KIF in the future.

The results of the research showed that due to the need to consider a comprehensive perspective in decision-making, it is necessary to first extract indicators related to the sustainable ARIH, then make decisions using an interdisciplinary futures studies research method through the opinions of future generations. In this research, considering the rapid population growth in Karaj, as well as the threats caused by climate change, it is necessary to plan for different futures of the KIF. Holding a future design workshop with the experts showed that the plausible, possible, and probable urban futures of the city of Karaj depend on factors such as the impact of climate change, optimizing energy consumption, and sociocultural factors such as demographic issues. Additionally, analyzing the scenarios through TDA made it easier to identify relationships among them and figure out their similarities and differences. The common solutions for preserving and revitalizing the KIF focus on sustainability and energy efficiency solutions, continuous monitoring of operations, complex planning and implementation challenges, the necessity of public participation, green space design, and reducing environmental impacts in the construction or reconstruction process. The most important differences between the scenarios can be found in the characteristics of the economic and social situation, the quality of implementation and energy efficiency solutions, public participation approaches, the role of green space, the level of access to financial resources and technology, and the performance of the KIF on an urban scale after renovation (Figure 7).

Although adaptive reuse of the KIF in the scenarios is dependent on economic conditions and inflation in Iran, from the perspective of the IFGs, this issue is not among the goals, while focusing on non-monetary aspects in economic dimensions is a priority. Unlike Yang et al. (2025), who focus on carbon reduction through smart and active energy systems, the presented scenarios, even in Scenario 3, emphasize Iranian vernacular strategies and passive systems like Persian gardens and site orientation. Also, since the KIF has never been active, its historical aspects become more highlighted in the second scenario. Unlike other industrial heritage sites that have been active in the past, KIF does not have many stories to tell and has a high potential for making history to be transferred to future generations. On the other hand, due to the diversity of existing structures, incompleteness of the structures, and the suitable urban location, there is the possibility of integration into the urban fabric in the future, and it can serve as an urban catalyst for future developments.

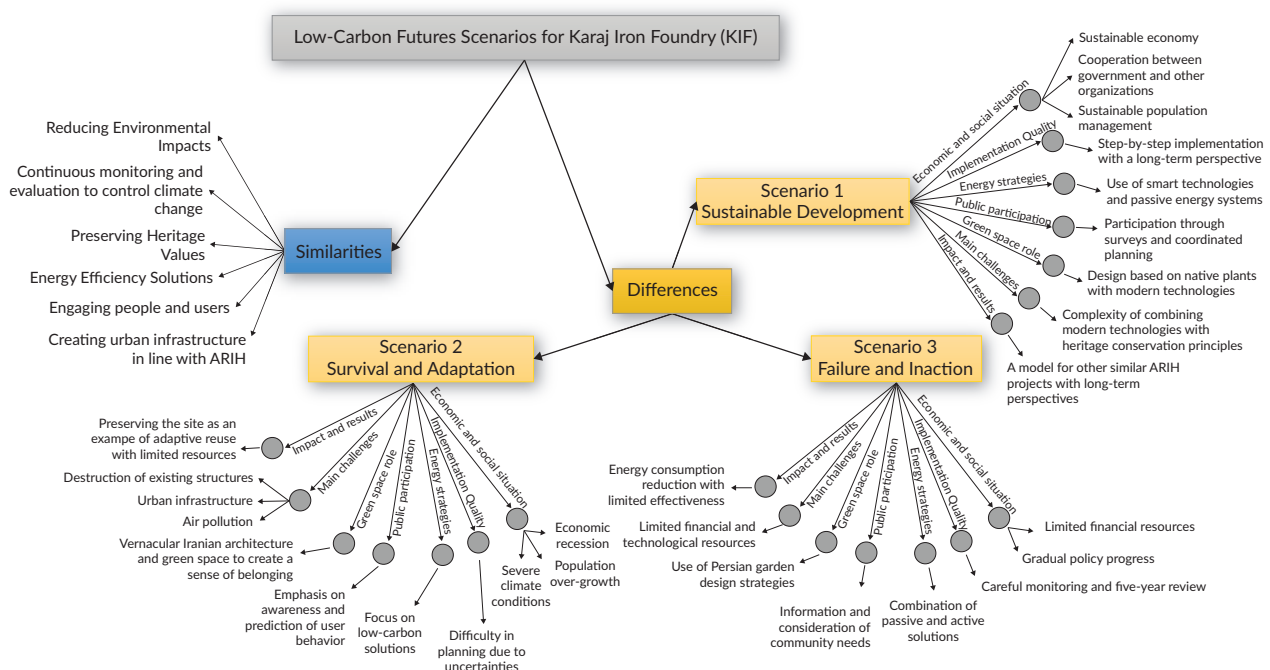


Figure 7. TDA for defining similarities and differences between scenarios based on the future design workshop session.

Previous studies on providing energy efficiency solutions for ARIH have ignored future generations' needs and have achieved different results. Sotodeh and Ghobadian (2023) used a similar method to extract indicators for the KIF adaptive reuse, but the weighting of the indicators and the priorities differ from the results of the present study. The priority of the indicators in their study is: "environment," "economy," "socio-cultural," "technology," and "process." While in our study, on the other hand, in which the perspectives of IFGs were used, the "process" category is of priority. Additionally, Sotodeh and Ghobadian (2022) presented modernisation solutions for adaptive reuse of the KIF, which reflect the perspective of the current generation. In addition, this study recommends using skylight as a strategy without explaining what problem this solves. Moreover, financing is proposed as a solution, whereas in our study, securing financial resources for adaptive reuse is one of the main challenges and a key factor for shaping the scenarios.

The authors conducted interviews with two environmental experts to ensure that the scenarios are in line with environmental issues and reflect a more comprehensive approach to technical aspects. The insights of the experts highlighted the need to address issues such as wastewater management, waste disposal, and urban sewage systems in the later stages of scenario making, especially by further analyzing uncertainties. Furthermore, the findings of the interviews emphasized the importance of assessing noise and air pollution after determining the final use of each building. Moreover, the integration of carbon sequestration strategies into the vegetation design of the Iranian garden in Scenarios 2 and 3 was identified as a pivotal element for reducing carbon dioxide emissions. Proposed strategies align with Iran's national climate policies, including the National Climate Change Strategy Program (National Climate Change Office et al., 2016), the Seventh Development Plan developed by the Islamic Council Research Center (2023), and the RCICA (2023).

Visioning through scenario-making with the perspective of the IFGs and examining urban and climate issues are among the key factors in the process of ARIH. The results of the present study are useful for

policymaking bodies to integrate and complete the national heritage conservation laws of Iran. In particular, the 2050 scenarios propose futuristic strategies in different scenarios for the adaptive reuse of the industrial heritage of Iran, which helps the Cultural Heritage, Handcrafts, and Tourism Organization of Iran manage the budget by the weighted indicators. Moreover, the FD-DoA method provides an innovative research method for long-term, futuristic decision-making for ARIH. The innovation of this study lies in a balanced perspective, which provides energy efficiency solutions of industrial heritage in line with urban future scenarios and enables researchers to make better decisions at each stage.

While the expert-centric future design workshop ensures the technical and academic rigor for KIF adaptive reuse, it still needs the policymakers and local citizens' opinions as IFGs. However, this process was not feasible in this study because of the need for public education and raising local citizens' awareness. This limitation can be addressed in the next phases of the project.

Future research could incorporate embodied carbon calculations when data on material usage, renovation plans, and final use of each building become more specific. This would complement the current qualitative scenario analysis and provide a more comprehensive quantitative evaluation of adaptive reuse projects.

9. Conclusion

The results were able to show how the ARIH site—the KIF—can play a role in creating a low-carbon city and achieving the goal of energy efficiency. Common sustainable futuristic solutions for preserving and adaptive reuse of such valuable heritage, applicable across all future scenarios, were presented in five categories: the quality of implementation, access to resources, energy strategies, public participation, and the role of green space. Also, due to the complexity of this process, the novel mix methodology presented in this article (FD-DoA) is effective in long-term creative visioning, considering future climate predictions. The extracted indicators show the necessity for Iran to adopt phased adaptive reuse programs (2025–2050). Moreover, the results of this study provide a clear roadmap for Iranian policymakers to establish a national industrial heritage conservation charter. To reach this aim, capacity-building programs with multi-stakeholder collaboration and the FD-DoA decision-making method are highly recommended. Therefore, by implementing the futuristic methods in KIF, Iranian policymakers can create a replicable model for other valuable industrial heritage sites in Iran to contribute to a low-carbon future through ARIH. Moreover, the results necessitate redefining sustainability in heritage contexts: from “do not harm” to “active legacy-building,” where current generations manage heritage as a treasure for future generations, which shows a paradigm shift in line with the “futurability” framework. In this regard, the current generations must sacrifice their desires for the interests of future generations and avoid actions that have immediate results.

Acknowledgments

The authors would like to express their sincere gratitude to all the participants of the workshop and those who generously dedicated their time to complete the research questionnaire.

Funding

Publication of this article in open access was made possible through the institutional membership agreement between the Technische Universität Berlin and Cogitatio Press.

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Data from the questionnaires and workshop sessions in this study are not publicly available due to privacy considerations, but are available upon reasonable request from the corresponding author.

LLMs Disclosure

LLM tools were used in this work.

References

- Abd Elgawad, S. M., Hegazi, Y. S., Mohamed, M. A., Elshanwany, H., & Zamel, A. A. (2025). Heritage building reuse in Egypt: Achieving a balance between energy efficiency and value preservation. *Journal of Engineering Research*. Advance online publication. <https://doi.org/10.1016/j.jer.2025.02.003>
- Afsahhosseini, F. (2024). The impact of Iran's urban heritage on sustainability, climate change and carbon zero. *Environment, Development and Sustainability*, 27, 12351–12391.
- Angrisano, M., Nocca, F., & Scotto Di Santolo, A. (2024). Multidimensional evaluation framework for assessing cultural heritage adaptive reuse projects: The case of the seminary in Sant'Agata de'Goti (Italy). *Urban Science*, 8(2), Article 50.
- Arfa, F. H., Lubelli, B., Quist, W., & Zijlstra, H. (2024). A model of the adaptive reuse process of heritage buildings: Validation on four cases in the Netherlands. *Design Studies*, 91, Article 101252.
- Aslani, F., Amini-Hosseini, K., & Fallahi, A. (2018). Evaluation of physical resilience of Karaj City, Iran, against earthquake. *Scientific Journal of Rescue & Relief*, 11(1), 63–71.
- Barone, G., Vardopoulos, I., Attia, S., & Vassiliades, C. (2024). Optimizing energy-efficient building renovation: Integrating double-skin façades with solar systems in the Mediterranean landscape. *Energy Reports*, 12, 2933–2945.
- Bildarchiv der Philipp Holzmann AG. (1939–1940). *Hüttenwerk Keredj (Teheran, Iran)* [Archival photos]. <https://holzmann-bildarchiv.de/bestandsubersicht/bauprojekte/huttenwerk-keredj-teheran-iran>
- Blagojević, M. R., & Tufegdžić, A. (2016). The new technology era requirements and sustainable approach to industrial heritage renewal. *Energy and Buildings*, 115, 148–153.
- Boostani, P., & Sadeghiha, M. (2022). Identification of critical uncertainties in Tehran in order to achieve the development of low carbon city by using scenario writing method. *Cleaner Engineering and Technology*, 6, Article 100405.
- De Santoli, L. (2015). Guidelines on energy efficiency of cultural heritage. *Energy and Buildings*, 86, 534–540.
- Dezfuli, R. R., Mehrakizadeh, M., Najar, B. S. A., Bazazzadeh, H., & Mahdavinejad, M. (2024). Geometric investigation of entrance proportions of houses from the Qajar to the beginning of the early Pahlavi in Dezful City (1789–1979). *Frontiers of Architectural Research*, 13(1), 57–78.
- Gall, T., Vallet, F., & Yannou, B. (2022). How to visualize futures studies concepts: Revision of the futures cone. *Futures*, 143, Article 103024. <https://doi.org/10.1016/j.futures.2022.103024>
- Gharaati, F., Mahdavinejad, M., Nadolny, A., & Bazazzadeh, H. (2023). Sustainable assessment of built heritage adaptive reuse practice: Iranian industrial heritage in the light of international charters. *The Historic Environment: Policy & Practice*, 498–532. <http://doi.org/10.1080/17567505.2023.2261328>
- Ghazi, B., Salehi, H., Cheshami, M., Zeydalinejad, N., & Linh, N. T. T. (2025). Projection of climate change impact on main climate variables and assessment of the future of Köppen–Geiger climate classification in Iran. *Acta Geophysica*, 73(2), 2017–2027.

- Ghazi Moghadam, A., & Madahi, M. (2014). Nokhostin Karkhaneh-ye Zob-e Ahan dar Iran. *Sarvestan Electronic Magazine*, 2(5), 6–10.
- Ghorbani, F., & Sajadzadeh, H. (2024). Tasir-e Taghyirat-e Pushesh-e Giyahi bar Sheddad-e Jazireh-ye Garmay dar Shahr (Nemuneh-ye Moredi: Kalanshahr-e Karaj). *Motaleate Shahri*, 13(52), 3–16.
- Goodarzi, P., Ansari, M., Rahimian, F. P., Mahdavinejad, M., & Park, C. (2023). Incorporating sparse model machine learning in designing cultural heritage landscapes. *Automation in Construction*, 155, Article 105058. <https://doi.org/10.1016/j.autcon.2023.105058>
- Grazuleviciute-Vileniske, I., & Zmejauskaite, D. (2025). 'Archeology' of hidden values of underutilized historic industrial sites in context of urban regeneration and nature-based solutions. *Buildings*, 15(2), Article 205. <https://doi.org/10.3390/buildings15020205>
- Guidetti, E., & Ferrara, M. (2023). Embodied energy in existing buildings as a tool for sustainable intervention on urban heritage. *Sustainable Cities and Society*, 88, Article 104284.
- Gustafsson, M., Dipasquale, C., Poppi, S., Bellini, A., Fedrizzi, R., Bales, C., Ochs, F., Sie, M., & Holmberg, S. (2017). Economic and environmental analysis of energy renovation packages for European office buildings. *Energy and Buildings*, 148, 155–165.
- Hara, K., Kitakaji, Y., Sugino, H., Yoshioka, R., Takeda, H., Hizen, Y., & Saijo, T. (2021). Effects of experiencing the role of imaginary future generations in decision-making: a case study of participatory deliberation in a Japanese town. *Sustainability Science*, 16, 1001–1016.
- Hara, K., Yoshioka, R., Kuroda, M., Kurimoto, S., & Saijo, T. (2019). Reconciling intergenerational conflicts with imaginary future generations: Evidence from a participatory deliberation practice in a municipality in Japan. *Sustainability Science*, 14, 1605–1619.
- Holtorf, C. (2022). Teaching futures literacy for the heritage sector. In K. Fouseki, M. Cassar, G. Dreyfuss, & K. Ang Kah Eng (Eds.), *Routledge handbook of sustainable heritage* (pp. 527–542). Routledge.
- Holtorf, C., & Bolin, A. (2022). Heritage futures: A conversation. *Journal of Cultural Heritage Management and Sustainable Development*, 14(2), 252–265.
- Hosseini, S. M., Saifoddin, A., Shirmohammadi, R., & Aslani, A. (2019). Forecasting of CO2 emissions in Iran based on time series and regression analysis. *Energy Reports*, 5, 619–631.
- Hosseinizadeh Lotfi, F., & Fallahnejad, R. (2010). Imprecise Shannon's entropy and multi attribute decision making. *Entropy*, 12, 53–62.
- Huang, Y., Wang, F., Hiscock, A. V., Satyarthi, J., & Smith, H. (2025). Including embodied carbon in assessing renovation options for industrial heritage buildings: A review and case studies. *Sustainability*, 17(1), Article 72.
- International Energy Agency. (2025). *Understanding energy end uses—Iran*. <https://www.iea.org/countries/iran/efficiency-demand>
- Iran Renewable Energy Association. (2022). *The first rank for Iran in the intensity of energy consumption*. <https://irrea.ir/blog/%D8%A7%D8%AE%D8%A8%D8%A7%D8%B1/%D8%B1%D8%AA%D8%A8%D9%87-%D8%A7%D9%88%D9%84-%D8%A8%D8%B1%D8%A7%DB%8C-%D8%A7%DB%8C%D8%B1%D8%A7%D9%86-%D8%AF%D8%B1-%D8%B4%D8%AF%D8%AA-%D9%85%D8%B5%D8%B1%D9%81-%D8%A7%D9%86%D8%B1%DA%98%DB%8C>
- Islamic Council Research Center. (2023). *Barnam-ye Haftom-e Tose'e*. <https://rc.majlis.ir/fa/news/show/1776775>
- Kamijo, Y., Komiya, A., Mifune, N., & Saijo, T. (2017). Negotiating with the future: Incorporating imaginary future generations into negotiations. *Sustainability Science*, 12(3), 409–420.
- Kiani, H., & Kamangar, M. (2022). A survey on the Koppen climate classification of Iran in 1975 and comparing

- it with the CSIR model outputs for the years 2030, 2050, 2080 and 2100 under the A1B and A2 scenarios. *Arabian Journal of Geosciences*, 15(2), Article 199.
- Lajvardi, H. (1985). *Iran oral history in Harvard University: interview with Mohammad Yeganeh*, New York. <https://curiosity.lib.harvard.edu/iranian-oral-history-project>
- Mahdavinejad, M., Gharaati, F., & Galil, M. I. Z. M. (2025). Anticipating the future of Iranian cities: High-tech versus nature-based solutions. In S. González-Arellano & B. Gandlgruber (Eds.), *Cities as anticipatory systems* (pp. 103–125). Springer.
- Miller, R. (2018). Futures Literacy Laboratories (FLL) in practice: An overview of key design and implementation issues. In R. Miller (Ed.), *Transforming the future: Anticipation in the 21st century* (pp. 95–109). Routledge.
- Miller, R., Poli, R., & Rossel, P. (2013). *The discipline of anticipation: Exploring key issues* (Bellagio Document 4: Working Paper 1). UNESCO.
- Monghasemi, S., Nikoo, M. R., Fasaee, M. A. K., & Adamowski, J. (2015). A novel multi criteria decision making model for optimizing time–cost–quality trade-off problems in construction projects. *Expert Systems with Applications*, 42(6), 3089–3104.
- Nakagawa, Y., Mori, M., Yamada, M., Hata, Y., Sugimoto, T., & Saijo, T. (2024). Infrastructure decommissioning: A brief report on embracing future generations' perspectives to avoid intergenerational procrastination. *Sustainability*, 16(24), Article 10840.
- Naseri, N., Hosseinzadeh Niri, M., & Mostafazadeh, R. (2025). Tahlil-e Keyfiat-e Fazaye Sabz-e Shahrestan-e Karaj ba Estefade az Shakhes-e Ekologi-ye Sanjesh az Door (RSEI). *Journal of Geography and Environmental Studies*, 14(53), 40–55.
- National Climate Change Office, Human Environment Deputy, & Environmental Protection Organization of Iran. (2016). *Barnameh-ye Rahbord-e Melli-ye Taghir-e Eghlim*. <https://climatology.ir/wp-content/uploads/2018/10/climatechange.pdf>
- Nishimura, N., Inoue, N., Masuhara, H., & Musha, T. (2020). Impact of future design on workshop participants' time preferences. *Sustainability*, 12(18), Article 7796.
- Ouf, A. (2024). Urban planning for the futures; urban foresight. *Ain Shams Engineering Journal*, 15(12), Article 103070.
- Pavlović, J., Šabanović, A., & Ćuković-Ignjatović, N. (2022). Energy efficiency improvement in industrial brownfield heritage buildings: Case study of “Beko.” In E. Arbizzani, E. Cangelli, C. Clemente, F. Cumo, F. Giofrè, A. M. Giovenale, M. Palme, & S. Paris (Eds.), *International Conference on Technological Imagination in the Green and Digital Transition* (pp. 821–830). Springer.
- Poli, R. (2017). Introducing anticipation. In R. Poli (Ed.), *The handbook of anticipation* (pp. 1–14). Springer.
- Ranjazmay Azari, M., Bemanian, M., Mahdavinejad, M., Körner, A., & Knippers, J. (2023). Application-based principles of Islamic geometric patterns; state-of-the-art, and future trends in computer science/ technologies: A review. *Heritage Science*, 11(1), Article 22.
- Research Center of the Islamic Consultative Assembly. (2023). *Barresi-ye Forsat-hā-ye Ejrā-ye Barname-ye Modiriyat-e Carbon dar Keshvar*.
- Saijo, T. (2019). Future design. In J. F. Laslier, H. Moulin, M. Sanver, & W. Zwicker (Eds.), *The future of economic design: Studies in economic design* (pp. 253–260). Springer.
- Saijo, T. (2023). Future design for sustainable nature and societies. In W. Leal Filho, A. M. Azul, F. Doni, & A. L. Salvia (Eds.), *Handbook of sustainability science in the future* (pp. 1751–1766). Springer.
- Saijo, T. (2024). Futurability, survivability, and the non-steady state in the intergenerational sustainability dilemma. *Politics and Governance*, 12. <https://doi.org/10.17645/pag.7749>
- Saijo, T. (2025). *Future design for creating a world worth inheriting*. Springer.

- Shaeri, J., Mahdavinejad, M., & Zalooli, A. (2022). Physico-mechanical and chemical properties of Coquina stone used as heritage building stone in Bushehr, Iran. *Geoheritage*, 14(3), Article 95.
- Shahbeik, A., Pourmazaheri, R., & Taheri, A. (2022). Barrasi-ye ravandhā-ye zamani va makāni-ye taghyirāt-e ālāyandehā-ye havā dar kelānshahr-e Karaj. *Environment and Interdisciplinary Development*, 7(76), 27–44.
- Shakarami, K., Rahnama, M., & Shokouhi, M. A. (2021). Tahlil-e Tose'e-ye Fazāyi-ye Form-e Shahr-i Karaj bā Ruykard-e Ayandeh-Pazhuhi. *Spatial Planning*, 11(4), 129–150.
- Shikh Mohammadi, A., & Hashemi, S. (2024). Navigating sociopolitical intricacies: Iran's energy transition pathways amidst global transformations. *Journal of World Sociopolitical Studies*, 8(2), 297–334. <https://doi.org/10.22059/wsps.2024.367504.1388>
- Sinou, M., Skalkou, K., Perakaki, R., Jacques, S., & Kanetaki, Z. (2023). Holistic strategies based on heritage, environmental, sensory analysis and mapping for sustainable coastal design. *Sustainability*, 15(13), Article 9953.
- Sotodeh, S., & Ghobadian, V. (2022). Tabyin-e Mo'aser-Sazi va Entebaq-e Sistemi-ye Miras-e San'ati-ye Alborz bar Asas-e Me'mari-ye Paydar. *Naqshejahan—Basic Studies and New Technologies of Architecture and Planning*, 12(1), 59–83.
- Sotodeh, S., & Ghobadian, V. (2023). Tadvin-e Charchub-e Eqdam va Mo'aser-Sazi-ye Majmu'e-ye Zob Ahane Karaj bar Asas-e Samaneh-ye Rotbeh-Bandi-ye Paydari DGNB. *Naqshejahan—Basic Studies and New Technologies of Architecture and Planning*, 13(1), 48–68.
- The International Committee for the Conservation of Industrial Heritage. (2003). *The Nizhny Tagil charter for the industrial heritage*.
- Trusiani, E., & D'Onofrio, R. (2024). Urban guidelines and strategic plan for a UNESCO world heritage candidate site: The historical centre of Sharjah (UAE). *Sustainability*, 16(17), Article 7461.
- Wang, Y., Zhu, R., Liu, J., Zheng, F., & Wu, C. (2023). Research on the industrial heritage community retrofitting design based on space network model of carbon. *Buildings*, 13(9), Article 2202.
- World Bank. (2025). *Electricity production from oil sources (% of total)—Iran, Islamic Rep.* <https://data.worldbank.org/indicator/EG.ELC.PETR.ZS?locations=IR>
- Yang, S., Ma, H., Li, N., Xu, S., & Guo, F. (2025). Energy-saving design strategies for industrial heritage in Northeast China under the concept of ultra-low energy consumption. *Energies*, 18(5), Article 1289.
- Yung, E. H., & Chan, E. H. (2012). Implementation challenges to the adaptive reuse of heritage buildings: Towards the goals of sustainable, low carbon cities. *Habitat International*, 36(3), 352–361.

About the Authors



Farzaneh Gharaati has obtained her PhD in architecture from Tarbiat Modares University, Tehran. Her dissertation focused on a decision support system for sustainability assessment and adaptive reuse of Iranian industrial heritage sites. Farzaneh is a member of the Modern Heritage and Future Legacy (MHFL) Research Hub at Tarbiat Modares University. She has conducted various research and interdisciplinary projects for the conservation and management of industrial heritage sites in Poland, Japan, and Iran through workshops with academics and local people.



Mohammadjavad Mahdavinejad is a founding member of HAREc–Oman, GRACE–Germany, and TICCIH–Iran, and an active member of Docomomo–International. He established the Modern Heritage and Future Legacy (MHFL) Research Hub to study how modern style, green aesthetics, international style values, and emerging technologies have influenced modern movement and future architecture in general, and the shared heritage of Iran and Germany in particular. After a successful career in Iran, Italy, and Germany, he now serves as a professor at the College of Engineering and Architecture, University of Nizwa, Oman.



Martin Meyer has been a PhD researcher at Technische Universität Berlin since 2017. Having worked with Violence Prevention Through Urban Upgrading in South Africa, with the GIZ in the Land Use and Settlement Program in Lesotho, and at the Building, Road, Housing & Urban Development Research Centre in Iran, he is passionate about international urbanism and the global exchange of knowledge. In his research, he focuses on housing provision in the Global South, modern heritage, the shared heritage of Iran and Germany, and participatory urban governance.



Tatsuyoshi Saijo is a professor of Kyoto University of Advanced Science and the director of the Future Design Research Center Lab in Japan. As a leading figure in the “Future Design” movement, he seeks to incorporate the perspectives of future generations into today’s policymaking. He has pioneered innovative deliberative experiments in which participants act as citizens of future generations to advocate for long-term social interests. This approach has influenced real-world policy in Japan and encouraged societies to prioritize sustainability and intergenerational equity. His efforts have been recognized internationally, including being named to Vox’s Future Perfect 50 list for 2023.

Sustainable Heritage Buildings: The Impact on Heritage Values, Energy Performance, and CO₂ Emissions

Maarten Vieveen¹ , Aron Banninga² , Tamizhselvan Munuswamy³ ,
and Tineke van der Schoor¹ 

¹ Research Centre for the Built Environment NoorderRuimte, Hanze University of Applied Sciences, The Netherlands

² Heritage Department, Libau, The Netherlands

³ Institute for Engineering, Hanze University of Applied Sciences, The Netherlands

Correspondence: Maarten Vieveen (m.c.vieveen@pl.hanze.nl)

Submitted: 22 April 2025 **Accepted:** 14 October 2025 **Published:** 26 November 2025

Issue: This article is part of the issue “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse” edited by Liam James Heaphy (University of Galway) and Philip Crowe (University College Dublin), fully open access at <https://doi.org/10.17645/up.i461>

Abstract

The Dutch national CO₂ emission targets for heritage buildings are a 60% reduction by 2040. However, holistic insights on the impact of this reduction on heritage values, energy performance, and CO₂ emissions are understudied. In this article, the impact in four heritage buildings by comparing the situation before and after the renovation process was studied. These energy reduction measures were part of a larger restoration or adaptive reuse process. We used archival documentation about the original design, assessed project documentation regarding the previous technical conditions of materials, and conducted fieldwork. The data was used in a heritage assessment, focussing on cultural, historical, architectural, ensemble, authenticity, and rarity values. Energy performance and CO₂ emissions were calculated based on desk research, fieldwork, and additional information provided by the owners. The CO₂ emission calculations included all materials that were removed or added during the construction process. We concluded that in some cases, heritage values have been degraded by the energy reduction measures, whereas in other cases, they were improved. In all cases, we found that heritage values were lost to a certain extent. The impact on energy performance and CO₂ emissions varied. CO₂ emissions for operational energy were reduced by approximately 52% on average, and CO₂ emissions for carbon energy were reduced by approximately 6% on average. Therefore, we conclude that energy-efficient restoration of heritage buildings considerably reduces environmental impact but comes at a cost to heritage values.

Keywords

CO₂ emission; energy performance; heritage values

1. Introduction

Following the ratification of the Paris Agreement (United Nations, 2015), the Dutch government (Eerste Kamer der Staten Generaal, 2017) adopted a participatory approach to enhance public support for climate targets. Specific policies were developed through sectoral climate tables (*Klimaattafels*), involving governmental agencies, companies, and non-governmental organisations. The Dutch Climate agreement (*Klimaatakkoord*) aims to reduce CO₂ emissions by at least 49% by 2030 and 95% by 2050, compared to 1990 levels (*Klimaatakkoord*, 2018a). These targets were further specified per sector, with the built environment sector focussing on insulation and heat transition strategies (*Klimaatakkoord*, 2018b).

In the Netherlands, approximately 120,000 heritage buildings are protected by national, provincial, and municipal authorities by the Heritage Act (OCW, 2024) and by local heritage policies (I&W, 2024). This allows governmental authorities to exempt listed buildings from climate policy targets when heritage values are threatened. Recognising the urgency for climate action, the heritage sector organised a specific climate table for heritage buildings and resulted in the Sustainable Built Heritage Roadmap (*Routekaart Duurzame Monumenten*). The Roadmap aims to reduce CO₂ emissions from energy consumption by 40% by 2030 and 60% by 2040 (*Routekaart Duurzaam Erfgoed*, 2019). Furthermore, the Roadmap called for a Sustainable Heritage Monitor to measure progress, which was implemented through a yearly survey of approximately 20,000 listed buildings.

1.1. Knowledge About Energy Reduction in Heritage Buildings

The European Green Deal (European Commission, 2019) and the Energy Performance of Buildings Directive ("Directive (EU) 2024/1275," 2024) emphasise the urgent need to reduce energy consumption and greenhouse gas emissions within the built environment, including heritage buildings. For historic buildings, NEN-EN 16883:2017 (Stichting NEN, 2017) provides guidelines to enhance energy performance while safeguarding cultural heritage values.

Several literature reviews on energy reduction in heritage buildings have been conducted in the past decade (Lidelöw et al., 2019; Webb, 2017). Webb argues that the literature indicates a shift in perception: from seeing energy reduction in heritage buildings as a threat to heritage to considering it as an opportunity to protect it. Furthermore, she showed that software can enhance the process of decision-making regarding energy reduction measures, for instance, by predicting risks and energy consumption via building energy models (BES; Webb, 2017). Both Webb (2017) and Lidelöw et al. (2019) concluded that energy reduction in heritage buildings necessitates a holistic approach, where energy reduction measures result from balancing multiple criteria. According to Webb (2017), the main criteria are heritage conservation and energy consumption. Wise et al. (2021) suggested to add occupant behaviour, because users of historical buildings often apply energy-saving living and heating strategies.

Baker et al. (2021) adopted a wider environmental perspective on energy reduction in heritage buildings through life cycle analysis (LCA). Based on interviews with stakeholders, they suggest including both operational carbon (energy consumption) and embodied carbon (materials). Dişli and Ankaraligil (2023) investigated how the life cycle of existing buildings could be prolonged by applying the concept of circular economy. See also Yang et al. (2014) and Potting et al. (2017). The concepts of heritage conservation and

circular economy share a common ground, namely reducing material loss, acting carefully, and ensuring the reversibility of changes to buildings (Costantino et al., 2024; Huuhka & Vestergaard, 2020). However, Huuhka and Vestergaard (2020) conclude that these concepts are based on different discourses and therefore can be complementary as well as contradictory. For example, repurposing ornaments combines well with a conservation approach, whereas urban mining does not. Serrano et al. (2022) investigated the concepts of restoration and circular economy through a case study of historic Danish farmhouses. By applying life-cycle assessment methodology, they quantified both operational carbon and embodied carbon impacts (Serrano et al., 2022). The study compared two design scenarios: an energy-efficient restoration design scenario, which incorporated energy reduction measures, and an energy renovation design scenario, which aimed for high energy performance targets and did not include heritage valuation. Their findings indicated a minor advantage for the energy-efficient restoration design scenario, as the associated CO₂ emissions were marginally lower than those of the renovation design scenario.

1.2. Dutch Practice of Sustainable Heritage

To support decision-making on energy reduction measures in heritage buildings, several instruments have been developed specifically for the Dutch heritage sector. Examples include the Sustainable Heritage Method (*DuMo-methode*; Nusselder et al., 2008; Van der Schoor, 2020; Van der Schoor et al., 2024), the Sustainably Improved Method (*methode Duurzaam Verbeterd*; De Jonge, 2011), and The Green Menu (*De Groene Menukaart* by *De Groene Grachten*; De Erfgoedstem, 2014). Additionally, the Foundation for High Quality of Restoration of Heritage Buildings (*Stichting Erkende Restauratiekwaliteit Monumenten*, ERM) developed guidelines for sustainable heritage advice (Stichting ERM, 2020). The Dutch methods and guidelines primarily focus on heritage conservation and energy consumption.

In the Netherlands, few studies have assessed the practical impact of energy reduction measures on heritage buildings. Generally, progress is monitored through the Dutch Sustainable Heritage Monitor, which supports the Sustainable Heritage Roadmap. This monitoring is based on annual surveys conducted from 2020 onwards (Right Marktonderzoek en Advies, 2022a, 2022b, 2024, 2025; Routekaart Duurzaam Erfgoed, 2022). In 2020, 264 owners of listed buildings participated; in 2021, this rose to 500 owners, and in 2022 and 2023, 555 owners took part. The Monitor provides insight into the users' appreciation of their heritage building, thermal comfort, and applied energy reduction measures. Furthermore, the available data included general figures about energy consumption. Throughout the years, the owners indicated the effect of energy reduction measures on heritage values and indicated the reduction in natural gas and electricity demands. However, for the primary aim of the Monitor—i.e., assessing progress on the climate targets—the results are limited. Only one PowerPoint presentation was published, which contained some figures that illustrate that, compared with 2018, both natural gas and electricity demand were reduced by approximately 19% by 2024 (De Vries & De Jong, 2024). The impact of energy reduction measures on heritage values was not assessed, nor was the material impact regarding CO₂ emissions.

1.3. Research Aim

The published data of the Roadmap are limited to energy reduction figures and lack insight into the decision-making process, especially regarding the impact on heritage values. A comprehensive understanding is essential to explain why certain outcomes were achieved (Lidelöw et al., 2019; Webb,

2017; Wise et al., 2021). Additionally, Serrano et al. (2022) successfully integrated heritage values into their study, which assessed energy performance and life-cycle carbon impacts using an LCA-based approach. Although their findings suggest that an energy-efficient restoration design scenario may yield more favourable environmental outcomes than an energy renovation design scenario that leaves out heritage valuation, this was not assessed in practice.

In this article, we present the findings of an evaluation study on recently restored Dutch heritage buildings where energy reduction measures were incorporated. Our aim was to assess the impact of these measures on heritage values, energy performance, and CO₂ emissions. Section 2 outlines our research approach, including the selection of case study projects and the assessment methods. Sections 3 to 6 detail the results of four case studies. Finally, Section 7 presents our conclusions.

2. Research Approach

We employed the case study method (Yin, 2009) to evaluate the impact of energy reduction measures in heritage buildings in the province of Groningen, the Netherlands. We applied a holistic approach, relying on Wise et al. (2021), who emphasised that technical performance studies on heritage buildings should consider both the social and technical contexts of these buildings. Furthermore, we adopted elements of the methodology of Serrano et al. (2022) to assess both energy performance (operational carbon) and life-cycle carbon impacts of materials (embodied carbon) using an LCA-based approach. This article specifically focuses on three aspects of the case studies: heritage values, energy performance, and CO₂ emissions.

Our case study buildings were part of a subsidy program in the province of Groningen: Major Maintenance, including Restoration of National Listed Buildings Groningen (*Groot onderhoud waaronder Restauratie Rijksmonumenten Groningen*; Provincie Groningen, 2024). An advantage of selecting case studies from this subsidy program was the availability of comprehensive project documentation. The province contacted subsidy recipients, and six building owners responded positively. Preference was given to buildings where the owner was actively involved in daily operation. As a result, one case was excluded because the owner leased the property to a commercial tenant. The remaining five buildings are privately owned and used as residences. In this article, only four case studies (Figure 1) are presented due to insufficient data for one project.



Figure 1. The case study buildings: Leens, Musselkanaal, Appingedam, and Spijk (Mark Sekuur, 2024).

The subsidy program of the province primarily subsidised restoration activities for up to 300,000 euros, of which 5,000 euros could be used for insulation measures. We estimated this was a welcome bonus for owners, though it provided only a limited boost for owners who have greater energy reduction ambitions. The data, research methodology, and findings were published in a practice-oriented report in Dutch (Vieveen et al., 2024).

2.1. Interviews

To explore the motivations and experiences of the building's owners, we conducted semi-structured interviews focussing on their reasons for buying the property, their initial ambitions and challenges, the energy consumption prior to the interventions, the energy reduction and restoration measures applied, and the role of various stakeholders throughout the design and construction process. The interviews were prepared by using project documentation that was provided by the province of Groningen, by carrying out brief archival research and internet searches, and by conducting preparatory phone calls with the owners. Interviews were conducted at locations preferred by the interviewees—typically in their homes, which also served as the buildings in the case studies. Three researchers carried out the interviews, each focussing on different aspects of the sustainable heritage process. All interviews were recorded, transcribed, and subsequently shared with the interviewees for review and correction of any inaccuracies.

2.2. Heritage Assessment

The heritage impact assessment included a study of the architecture and typology of the buildings. This involved desk research, using documentation provided by the province of Groningen and the owners, as well as additional archival research at local heritage agencies. Relevant literature on architectural styles and typologies was also consulted. Field research was conducted through on-site inspections of the buildings. Furthermore, oral histories—such as information about how previous owners used and modified the buildings—were shared by the owners during the interviews (see Section 2.1).

The heritage assessment involved a comparative analysis of heritage values across two timeframes. The original historic construction periods are described in the general introduction of the case study sections and include the significant alterations and defining characteristics of the building, up to the point when it was listed for its national importance. Timeframe 1 includes the *pre-intervention state*, representing the condition of the building immediately before the implementation of energy reduction measures. This included legal modifications (with permits) and unauthorised alterations (without permits) made since the building's heritage designation. Timeframe 2 includes the *current state*, reflecting the building after the energy reduction measures were applied.

We relied on the Dutch heritage valuation standard (RCE, 2024) to determine the heritage values. This standard includes five main categories:

- *Cultural historical value*: Reflects the narrative a building conveys about the past, including its age, its role in shaping local identity, and the emotional connection people may have to it.
- *Architectural historical value*: Pertains to the visual shape of buildings, such as their building typology, architectural style, and, in some cases, the influence of a notable architect on design and construction.
- *Ensemble value*: Connects the building to its location and immediate context, including its relationship to surrounding structures. This value considers whether the building is part of a coherent group or cluster, either functionally or visually.
- *Authenticity value*: The extent to which a building has remained unchanged since its original construction and whether its original function is still discernible. This criterion focuses on historical integrity.

- *Rarity value*: Concerns the uniqueness of a building, which may be expressed through its building typology. For example, a distinctive architectural style or distinctive ornaments that are uncommon for this type.

For scoring the impact of interventions on heritage values, we followed the Dutch Practical Guidelines for Building History Research (*Handboek Bouwhistorisch Onderzoek*; Stichting ERM, 2024), which uses a four-point scale:

- *Negative values*: The intervention has a detrimental effect on one or more heritage values. This may include the removal of original historic material in good condition or alterations that compromise significant visual characteristics.
- *Indifferent values*: The intervention has little to no impact on the values of the building.
- *Positive values*: Although not original, the intervention supports or enhances the building's heritage values—for example, by restoring original visual elements or using more appropriate materials.
- *High values*: The intervention makes a substantial contribution to the building's heritage values, such as restoring severely damaged original features or applying appropriate materials on a large scale.

The heritage assessment was conducted at multiple levels: individual building elements, broader architectural components, and the building as a whole. It considered both material integrity and visual heritage values. When the technical condition of building materials was found to be in poor condition and required replacement, they were classified as “lost” in terms of heritage value.

This study is restricted to the impact of energy reduction measures on heritage values. Other interventions—such as foundation improvements or adaptations for new uses—were excluded from the scope of this assessment. As a result, the overall heritage value assessment of all interventions on the building may differ from the findings presented in this article.

Although our heritage assessment approach is widely supported in the Netherlands, it inherently involves a degree of subjectivity. In this study, the assessment was conducted by a researcher with extensive experience in evaluating the impact of interventions on listed buildings in the Netherlands.

2.3. Energy Performance

We calculated the energy performance of each building for timeframe 1 and 2. For this part, we also used documents provided by the province of Groningen and the owners. Furthermore, we carried out on-site surveys of materials, energy systems, and envelope characteristics. Additional insights were drawn from the interviews with the owners (see Section 2.1), for example on wall constructions, thermal user behaviour, and indoor temperature patterns throughout the year.

We calculated the heated surface areas and volumes of each building based on architectural drawings. Building materials were inventoried through on-site inspections and supported by information provided by the owners regarding both the original construction and newly applied materials and energy systems.

For the energy performance calculations, we followed the recommendations of Wise et al. (2021) to develop a tailor-made baseline using a BES-model. This involved calibrating the modelled scenarios with actual energy consumption data.

Energy performance was assessed using the MESH tool (MESH Energy, 2024), an Excel-based steady-state BES-model for heritage applications. MESH calculates energy demand for heating, electricity use, and renewable generation. Where available, calibration was performed using metered data, and results were weather-normalised using degree-day correction to ensure comparability across different years.

All energy carriers were converted to kWh for comparability, using standard European conversion factors (European Environment Agency, 2019). Energy performance results are reported as absolute annual totals in kg CO₂e/m². Household electricity consumption was included where relevant. For photovoltaic (PV) systems, electricity was categorised into self-consumed and exported fractions, with transparent crediting rules applied. For biomass fuels (e.g., wood, pellets), biogenic CO₂ emissions were reported separately from fossil upstream emissions.

2.4. CO₂ Emissions

For the assessment of embodied carbon (changed materials), we used the LCA across five stages (Stichting NEN, 2012). We limited our calculations to:

- The construction stage (A1–A5), restricted to removing and adding materials, categorised as:
 - Restoration and maintenance (e.g., replacing the roof or reconstructing en-suite doors);
 - Modernisation (e.g., adding a kitchen or new internal walls);
 - Energy reduction measures (e.g., insulation or solar panels). When energy reduction measures were part of maintenance (e.g., replacing a broken window) or modernisation (e.g., a new insulated wall), the CO₂ emissions were not allocated to energy reduction measures.
- The energy consumption related to the use stage (B1–B7).

We argue that it is sufficient to calculate only these categories, since unchanged parts of the building will not affect environmental impacts differently after the interventions. Both embodied energy of existing materials, their maintenance, and end-of-life impacts remain constant.

The CO₂ emissions of the LCA stages were assessed using the MESH tool (MESH Energy, 2024). MESH calculates the environmental product declarations for material life-cycle impacts. To capture the time dimension, impacts were annualised using reference service lives (RSLs): 15–20 years for HVAC, 35–50 years for windows, and 50 years for insulation, instead of a uniform 30-year depreciation. RSLs and emission factors were derived from the Dutch National Environmental Database (Stichting Nederlandse Milieudatabase, n.d.).

3. Case Study 1: Rentenierswoning Leens

A *rentenierswoning* is a typical Dutch building type that was prominent around 1900. Wealthy farmers (*herenboeren*) would pass their farm on to their successor and retire in style. They often hired a well-known architect to design their private house in the latest architectural fashion in the village near the farm.

The *rentenierswoning* in Leens was built in 1910 and is valued as an example of its type. Its architectural historical values are found in a historicizing style with specific building features from a prominent design, such as valuable Art Nouveau ornaments. It is designed by notable architects Klaas and Gerhardus Hoekzema. Ensemble values are found in its prominent location at a crossroad. Furthermore, the building is part of an ensemble of multiple *rentenierswoningen*, that are characterised by a diversity of architectural styles. A notable feature is its relationship with a similarly designed *rentenierswoning* across the road, designed by architect W. Reitsema.

3.1. Heritage Assessment

3.1.1. Timeframe 1

The technical condition of the building in Leens was mixed. Several parts were in poor technical condition, such as the cavity wall anchors and roof tiles. Other parts were in remarkably good condition, such as the 100-year-old original wooden window frames and the wooden beams construction of the ground floor. As a result of the overall poor technical condition of the building, some materials needed to be replaced and could be considered lost.

The building was in a relatively authentic condition before the interventions were applied. The occurring loss of authenticity in this building was caused by the necessary replacement of historically significant materials that were in poor condition. This provided an opportunity for energy reduction measures that had virtually no effect on heritage values. Overall, the heritage values were high before the energy reduction measures were applied:

- *Cultural historical values*: Unchanged, thus highly valued;
- *Architectural historical values*: Unchanged, thus highly valued;
- *Ensemble values*: Unchanged, thus highly valued;
- *Authenticity*: The building is highly authentic, with regard to its floor plan, exterior elements, and interior features;
- *Rarity*: The *rentenierswoning* is relatively rare.

3.1.2. Timeframe 2

The current owners expressed great responsibility in their ambition: "We wanted to restore the house in such a way that it would last for at least another hundred years." They believed that incorporating energy reduction measures was essential to achieve this goal. To protect heritage values, the owners aimed to minimise or prevent the loss of historical materials and visual changes.

The following measures were applied:

- Exterior walls: Maintenance and applying cavity wall PIR granulate insulation;
- Windows: Replaced the single glazing with vacuum glass;
- Roof: Fully replacing the broken roof tiles and applying glass wool insulation;
- Modernisation: New bathroom and kitchen;

- Heating system: Applying a new highly efficient central heating boiler (natural gas), suitable for hydrogen energy in the future;
- Other systems: PV panels.

As part of the sustainable heritage strategy, the Restoration Ladder (*Restauratieladder*; Stichting ERM, 2019) concept was used in decision-making to prevent the loss of heritage values. For example, vacuum glass was used. The owners expressed their satisfaction with it:

We are very happy with the glass; due to its limited thickness, the original wooden frame and its detailing were preserved. Guests do not even see the tiny dots between the glass layers. The room is more comfortable, not only because of better insulation characteristics but also because traffic noise is almost absent.

Additionally, the building contained cavity walls, an early example of this building feature. These allowed reversible insulation granules to be applied. Overall, heritage values have remained high after the energy reduction measures were applied:

- *Cultural historical values*: The impact is negligible;
- *Architectural historical value*: The impact is negligible;
- *Ensemble value*: The impact is negligible;
- *Authenticity*: Some impact on the authenticity of the building due to the replacement of historic materials;
- *Rarity*: The impact is negligible.

A photo impression of the building after renovation is presented in Figure 2.



Figure 2. Case in Leens after the construction process (Mark Sekuur, 2024).

3.2. Energy Performance

The building's heated surface area (201 m²) and volume (656 m³) remained unchanged with the implementation of energy reduction measures. Heating behaviours were consistent across both timeframes: rooms are heated to 16°C when vacant and to 19°C when occupied.

Energy consumption figures for timeframes 1 and 2 are presented in Table 1. The applied energy reduction measures resulted in a 53% decrease in energy consumption and a 62% reduction of CO₂ emissions.

Table 1. Energy performance.

	Timeframe 1		Timeframe 2	
	kWh	kg CO ₂ e/m ²	kWh	kg CO ₂ e/m ²
Heating system	40,090	36	22,666	20
Other energy consumption	4,371	8	2,855	5
Energy generation	Not applicable	Not applicable	–4,761	–9
Total	44,461	44	20,760	17

3.3. CO₂ Emissions

Timeframe 1 includes the CO₂ emissions for energy consumption during the use stage (B1–7), which were calculated at 44 kg CO₂e/m². In timeframe 2 this changed to 17 kg CO₂e/m². The impact of the construction stages (A1–5) totalled at (2,220 kg CO₂e/yr or) 11 kg CO₂e/m² and is specified as follows:

- Restoration and maintenance: (1,485 kg CO₂e/yr or) 7 kg CO₂e/m²;
- General modernisation: (105 kg CO₂e/yr or) 1 kg CO₂e/m²;
- Primary energy reduction measures: (630 kg CO₂e/yr or) 3 kg CO₂e/m².

To determine the overall CO₂ emissions reduction, we combined the emissions from material changes with those from energy consumption. This resulted in a total reduction of 16 kg CO₂e/m², representing an approximately 37% reduction compared to timeframe 1.

4. Case Study 2: Church Musselkanaal

Since the eighteenth century, many protestant communities have separated themselves from the Dutch Protestant church. These separated churches would initially be housed in accommodation provided by church members, such as barns. By the early twentieth century, new churches started to be built. The choice of architect and architectural style tended to be used as a means of distinguishing themselves from other churches/communities.

The church community in Musselkanaal was a small church congregation that belonged to the *Nederlandse Protestanten Bond*, a liberal denomination. The liberal movement expressed itself with contemporary progressive expressionist architecture. Their new church, designed by A.H. Kleinenberg, was completed in 1926. Architectural historical values are found in the unchanged, originally designed hall-church in expressionistic brick *Amsterdam school* architecture, in a variation that is specific to Groningen. Both the architecture and detailing are meticulously crafted. The interior is almost fully original and an integral part of the design. Most of the buildings on Kerkstraat were constructed between 1925 and 1935, giving the street high ensemble values. Many buildings share architectural similarities, such as the school and the associated headmaster's house at the top of the street. Both the school and church are slightly set back from the street compared to the other buildings, emphasising their different functions.

4.1. Heritage Assessment

4.1.1. Timeframe 1

Since 2002, the church has not been used on a daily basis. Consequently, no changes were made to the church, and both the interior and exterior have remained largely authentic. Only the interior colours of the church have been altered in the past. Due to the building's lack of use, maintenance was neglected, resulting in material deterioration.

The church was in a moderate technical condition. The owner elaborated: "Some parts were in a poor condition, for example, the roof. Occasionally, tiles were falling off, which was a risk for the neighbours and their dog." Furthermore, due to the absence of heating, the interior walls had been affected by moisture, which resulted in damaged interior wooden panelling and window frames. Overall, the heritage values were high before the energy reduction measures were applied:

- *Cultural historical values*: Unchanged, thus highly valued;
- *Architectural historical values*: Unchanged, thus highly valued;
- *Ensemble values*: The buildings in the street have positive ensemble values;
- *Authenticity*: Highly valued due to a high degree of originality in both its interior and exterior;
- *Rarity*: The building is relatively rare.

4.1.2. Timeframe 2

The main plan was to both restore the building and initiate an adaptive reuse process to make the church suitable for living and a small enterprise. This involved transforming the church council chamber behind the church into an apartment and converting the main church area into a multifunctional space, to be used as a storage room for an antiques and curiosities business. The building was not insulated and only the council chamber was heated.

The following measures were applied:

- Exterior walls: Thin PIR insulation in partition walls;
- Windows and doors: Plexiglass front windows on the interior side of the stained-glass windows;
- Roof: Thin multi-layered insulation foil;
- Modernisation: Addition of bathroom, toilet, and kitchen;
- Heating system: A wood heating stove and a highly efficient central heating boiler.

The owner is satisfied with the result: "It was challenging to find tailor-made solutions for insulating the curved roof. The architectural detailing of the connection of the roof and front facade is very fragile. The knowledge and advice of the restoration architect were very important." The energy reduction measures improved the thermal comfort required for the new building's function, thereby enabling its conservation. However, these measures did impact the heritage values by altering the architectural design and replacing original materials. Note: all interventions are relatively reversible. It is evident that the decision-making process involved balancing the conservation of authentic elements with the need to adapt the building for

contemporary use. Without any changes, the building would likely have suffered further loss of heritage values. Overall, heritage values have remained high after the energy reduction measures were applied:

- *Cultural historical values*: The impact is negligible;
- *Architectural historical values*: A negative impact on visual values because of the visual effect of the insulation of interior walls and roof, and wood pellet stove. Note: These interventions are all relatively reversible;
- *Ensemble values*: The impact is negligible;
- *Authenticity*: A minor negative impact on authenticity values because of the loss of some original materials;
- *Rarity*: A minor negative effect due to the impact on the architectural, historical, and authenticity values. Note: These interventions are all relatively reversible.

A photo impression of the building after renovation is presented in Figure 3.

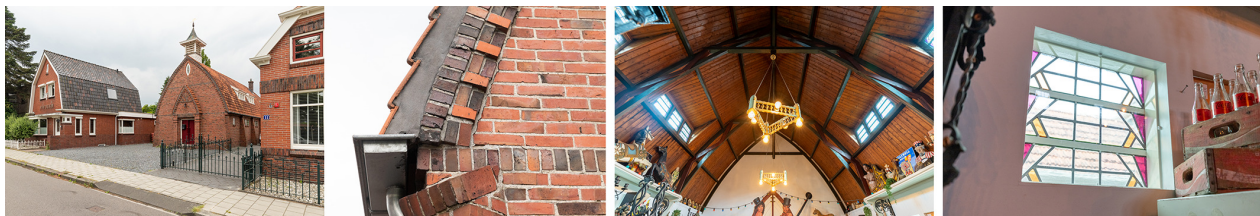


Figure 3. Case in Musselkanaal after the construction process (Mark Sekuur, 2024).

4.2. Energy Performance

The building's heated surface area and volume changed between both timeframes. In timeframe 1, the heated surface area was 74 m² and the volume 334 m³. In timeframe 2, these increased to 201 m² and 656 m³, representing a 1.9-fold increase in surface area and a 1.4-fold increase in volume. Heating behaviour was consistent across both timeframes: rooms are heated to 16°C when vacant, and to 19°C when occupied. The building is used only every other weekend, resulting in a usage intensity of approximately 29% (4 out of 14 days).

Energy consumption figures for timeframe 1 and 2 are presented in Table 2. The applied energy reduction measures resulted in a 14% decrease in energy consumption and a 63% reduction of CO₂ emissions.

Table 2. Energy performance.

	Timeframe 1		Timeframe 2	
	kWh	kg CO ₂ e/m ²	kWh	kg CO ₂ e/m ²
Heating system	1,899	5	1,612	1
Other energy consumption	272	1	255	0
Energy generation	Not applicable	Not applicable	Not applicable	Not applicable
Total	2,171	5	1,867	2

4.3. CO₂ Emissions

Timeframe 1 includes of the CO₂ emissions for energy consumption during the use stage (B1–7), which were calculated at 35 kg CO₂e/m². In timeframe 2, this changed to 20 kg CO₂e/m². The impact of the construction stages (A1–5) totalled at (2,921 kg CO₂e/yr or) 15 kg CO₂e/m² and is specified as follows:

- Restoration and maintenance: (2,250 kg CO₂e/yr or) 11 kg CO₂e/m²;
- General modernisation: (544 kg CO₂e/yr or) 3 kg CO₂e/m²;
- Primary energy reduction measures: (127 kg CO₂e/yr or) 1 kg CO₂e/m².

To determine the overall CO₂ emissions reduction, we combined the emissions from material removal and addition with those from energy consumption. This resulted in a total major increase of 11 kg CO₂e/m², representing an approximately 224% increase compared to timeframe 1. This is explained by the low CO₂ emissions for energy consumption compared to the changed building materials.

5. Case Study 3: Villa Appingedam

The villa holds high cultural historical value as an example of dwellings of the wealthy bourgeoisie around 1900 in Appingedam. The affluence of some citizens of Appingedam is reflected in the large villa, the carriage house, and the landscaped garden. This prosperity is also reflected in the architectural historical values. The villa and attached carriage house are extraordinary examples of the villa architecture from about 1900 in the province of Groningen. The architect is presumed to have been Geert Kruizinga (1863–1949). The design includes Neo-Renaissance elements, with the interior featuring various highly valuable Neo-Renaissance elements and some later-added Jugendstil decorations. Regarding ensemble values, the location of the villa is special and highly iconic, situated at the crossroads of multiple main roads. Additionally, there is a valuable spatial-visual relation with the monumental landscape garden.

The villa underwent multiple changes throughout the twentieth century. The first major alteration occurred when the building was used for hospitality purposes in the 1960s and a dance hall was added to the western part of the cellar. To this end, the cellars' ceiling had to be elevated by one meter, affecting the styled room, the old kitchen, and the intermediate room on the ground floor. The old staircase was removed and a new one was installed in the intermediate room and the old kitchen. In the 1980s, the carriage house was used as a dental clinic.

5.1. Heritage Assessment

5.1.1. Timeframe 1

The exterior and interior of the monumental villa and carriage house have been changed several times since 1900. Nevertheless, the buildings remain virtually authentic, with the exception of the western part of the cellar and ground level rooms of the villa.

The current owners purchased the villa in 2010 with the ambition of restoring it to its original design and modernise it without compromising its heritage values. The technical condition of the buildings varied

between moderate to reasonable; the sunroom was in poor condition, as were the roof and the paintwork on the window frames, mouldings, and especially the lionhead ornaments around the villa. The owners stated:

For us, it was impossible to apply all interventions at once; that was far too costly. Therefore, we phased our ambitions. As soon as we had amassed a sufficient budget, we would apply the next set of interventions. Furthermore, an expert supported us in developing the design, obtaining the building permit, and guiding the construction process of large restoration interventions.

To summarise, the following measures were applied:

- Floors: Lifting part of the floor of the ground level of the villa to its original level, including alterations on adjacent walls. PIR granulate in the space underneath the first floor of the villa;
- Exterior walls: In the kitchen, glass wool insulation in partial walls. Repairing stone ornaments in the masonry brick walls of the villa. Restoring the timber walls of the sunroom;
- Windows: Glass was replaced with HR++ glass of the villa, including replacing the yellow glass windows in the sunroom. Window and door frames were repaired and painted;
- Roofs: Damaged roofing was replaced and the roofs were insulated with glass wool. The villa's hatch panel to the roof was repaired;
- Internal walls: Glass wool was applied in the timber framed walls on the first floor;
- Maintenance and restoration: Restoring (rebuilding) an old staircase in the villa;
- Modernisation: Replacing the villa's kitchen and adding a professional kitchen in the carriage house;
- Heating system: Two highly efficient central heating boilers (in the villa and in the carriage house). Restoring the wood stove in the living room. An electric heating system on the first floor;
- Other systems: PV panels on the villa.

Because the majority of heritage values was still intact, overall, the heritage values were highly valued before energy reduction measures were applied:

- *Cultural historical values*: Unchanged, thus highly valued;
- *Architectural historical values*: Although several elements have been altered, the overall design remains, including Neo-Renaissance elements and some later-added Jugendstil decorations;
- *Ensemble values*: Unchanged, thus highly valued;
- *Authenticity*: The villa has positive values as most of the original design and materials of both the interior and exterior are largely intact with minor changes and reconstructions due to the different functions the building has had over the years;
- *Rarity*: The villa is relatively rare.

5.1.2. Timeframe 2

The restoration included modernisation but did not involve large-scale energy reduction measures. The applied measures had a minor impact on heritage values, as the primary goal was to reinforce these heritage values. The owners revealed:

You know you did not buy a modern energy-efficient building, therefore we accepted that thermal comfort in the villa is somewhat limited and energy costs are relatively high. We have chosen to apply a zoning concept, which means that we only heat the rooms that we use.

These types of energy reduction measures resulted in remaining high heritage values:

- *Cultural historical values*: The impact is negligible;
- *Architectural historical values*: The villa is restored to its original function as residential house. The impact is negligible;
- *Ensemble values*: The impact is negligible;
- *Authenticity*: The impact is negligible, with the exception of replaced materials and the detailing of the stairs due to wall insulation;
- *Rarity*: The impact is negligible.

A photo impression of the building after renovation is presented in Figure 4.



Figure 4. Case in Appingedam after the construction process (Mark Sekuur, 2024).

5.2. Energy Performance

The building's heated surface area (389 m²) and volume (1,227 m³) remained unchanged after the implementation of energy reduction measures. Heating behaviour was consistent across both timeframes: rooms are heated to 15°C when vacant and to 18°C when occupied.

Energy consumption figures for timeframe 1 and 2 are presented in Table 3. The applied energy reduction measures resulted in a 37% decrease in energy consumption and a 41% reduction of CO₂ emissions.

Table 3. Energy performance.

	Timeframe 1		Timeframe 2	
	kWh	kg CO ₂ e/m ²	kWh	kg CO ₂ e/m ²
Heating system	68,575	31	46,563	22
Other energy consumption	3,750	4	3,750	4
Energy generation	Not applicable	Not applicable	–5,000	–5
Total	72,325	35	45,313	20

5.3. CO₂ Emissions

Timeframe 1 includes the CO₂ emissions for energy consumption during the use stage (B1–7), which were calculated at 35 kg CO₂e/m². In timeframe 2, this changed to 20 kg CO₂e/m². The impact of the construction stages (A1–5) totalled at (4,684 kg CO₂e/yr or) 15 kg CO₂e/m² and is specified as follows:

- Restoration and maintenance: (3,906 kg CO₂e/yr or) 10 kg CO₂e/m²;
- General modernisation: (542 kg CO₂e/yr or) 1 kg CO₂e/m²;
- Primary energy reduction measures: (1,237 kg CO₂e/yr or) 3 kg CO₂e/m².

To determine the overall CO₂ emissions reduction, we combined the emissions from material removal and addition with those from energy consumption. This resulted in a total reduction of 0 kg CO₂e/yr, i.e., 0% reduction compared to timeframe 1.

6. Case Study 4: Farm Spijk

The farm building from 1900 holds significant cultural historical value as a representative example of agricultural buildings in the province of Groningen around the turn of the century. Its substantial size and the richly detailed interior of the front house reflect the lifestyle and status of the small group of wealthy farmers in this region during that period. Furthermore, the farm building holds significant architectural historical values as an example of the regional farm type of *dwarshuisboerderij*, a farm where the house is transversely oriented in front of the barn. The story of the wealthy farmers is reflected in the Eclectic architecture of the *dwarshuis*' exterior and interior that exhibit exceptionally rich detailing. Furthermore, it is reflected in the ensemble values: the tree-filled and in part moated farm property retains its original character in its iconic location just outside the village of Spijk, situated on one of the oldest exit roads. Its significance is further enhanced by the local ensemble of a wide canopy of trees, drive-up avenue, moat enclosure with pedestrian bridge, and decorative garden.

In 1962, the farm lost its function, and it was bought by an artist couple who respected its heritage values. Before the building was listed, a watchtower was placed on the barn, and an atelier was built inside it.

6.1. Heritage Assessment

6.1.1. Timeframe 1

The previous owners made several modifications to the interior of the farm, such as converting the attic of the old house (located between the front house and barn) into a bedroom and also modernising the atelier room in the barn. The exterior of the farm remained in an almost original condition prior to the implementation of energy reduction measures. The cessation of the agricultural activities did not lead to significant alterations or loss of heritage values. Many of the historic materials, the building's layout, and the architectural details were still intact.

Due to prolonged neglect of maintenance needs, some historical materials were severely damaged and irreparable, such as window frames, the roof, and areas affected by leaks and insects. Additionally, structural issues arose from both previous poor interventions and soil subsidence.

Overall, the heritage values were high before energy reduction measures were applied:

- *Cultural historical values*: Unchanged, thus highly valued;
- *Architectural historical values*: The valued elements are largely intact, thus highly valued;
- *Ensemble values*: Although the building lost its agricultural function, the property retains its original character, thus highly valued;
- *Authenticity*: The building holds positive authenticity values due to the largely originality of the exterior, floor plan, and decorative interior elements;
- *Rarity*: The *dwarshuisboerderij* is relatively rare.

6.1.2. Timeframe 2

The current owners initiated a large-scale restoration and maintenance process. The sustainability ambitions were significant, but they did not want to compromise heritage values. Therefore, energy reduction measures were applied with caution, ensuring that heritage values were not adversely affected. The owners stated:

We were impressed by the beauty of the front house and compromising its values was out of the question. But we also needed to be able to live here comfortably. Therefore, we used a living area in the former atelier in the barn as a winter residence. It avoided applying major interventions in the front house.

The following measures were applied:

- *Foundation*: A new foundation was applied in the conservatory;
- *Exterior walls*: Damaged walls were repaired;
- *Windows*: Glass was replaced with HR++ glass. Window and door frames were repaired and painted;
- *Roof*: The roof of the front house was repaired and glass wool was applied. The barn's roof plates (partly asbestos) were replaced by a thatched roof. Furthermore, the roof construction near the sunroom and part of the front house was strengthened;
- *Maintenance and restoration*: Various minor maintenance work;
- *Modernisation*: Upgrading the former atelier space in the barn into a well-insulated living room for the cold season;
- *Heating system*: A high-efficiency heating boiler for the front house and a heat stove in the former atelier space in the barn.

The owners are satisfied with the results:

The historic atmosphere of the front house was preserved; it is a pleasure to live here. Although, we would like to find a way to further improve the use of sustainable energy. Currently, we cannot and do not want to apply solar panels on the thatched roof or in the garden that is full of trees.

The impact of energy reduction measures on heritage values was negligible; heritage values remained high:

- *Cultural historical values*: The impact is negligible;
- *Architectural historical values*: A little to no negative effect on the architectural values and in part contributed to their enhancement with the restoration of the thatched roof of the barn;
- *Ensemble values*: The impact is negligible on the ensemble values;
- *Authenticity*: Some loss of certain authenticity values, while others contributed to their enhancement;
- *Rarity*: The impact is negligible.

A photo impression of the building after renovation is presented in Figure 5.



Figure 5. Case in Spijk after the construction process (Mark Sekuur, 2024).

6.2. Energy Performance

The buildings' heated surface area and volume changed slightly between both timeframes. In timeframe 1, the heated surface area was 333 m² and the volume 974 m³. In timeframe 2, these increased to 360 m² and 1,031m³, respectively—representing a 1.1-fold increase in both metrics. Heating behaviour was consistent across both timeframes: rooms are heated between 10–15°C when vacant and to 19°C when occupied. Moisture levels are actively monitored, allowing the temperature to be increased when critical values are reached, particularly during the cold season.

Energy consumption figures for timeframe 1 and 2 are presented in Table 4. The applied energy reduction measures resulted in a 12% decrease in energy consumption and a 47% reduction of CO₂ emissions.

Table 4. Energy performance.

	Timeframe 1		Timeframe 2	
	kWh	kg CO ₂ e/m ²	kWh	kg CO ₂ e/m ²
Heating system	30,818	16	28,066	9
Other energy consumption	2,656	3	1,519	2
Energy generation	Not applicable	Not applicable	Not applicable	Not applicable
Total	33,474	19	29,585	10

6.3. Assessment of CO₂ Emissions

Timeframe 1 includes the CO₂ emissions for energy consumption during the use stage (B1–7), which were calculated at 19 kg CO₂e/m². In timeframe 2 this changed to 10 kg CO₂e/m². The impact of the construction stages (A1–5) totalled at (2,440 kg CO₂e/yr or) 7 kg CO₂e/m² and is specified as follows:

- Restoration and maintenance: (1,455 kg CO₂e/yr or) 4 kg CO₂e/m²;
- General modernisation: (536 kg CO₂e/yr or) 1 kg CO₂e/m²;
- Primary energy reduction measures: (449 kg CO₂e/yr or) 1 kg CO₂e/m².

To determine the overall CO₂ emissions reduction, we combined the emissions from material removal and addition with those from energy consumption. This resulted in a total reduction of 2 kg CO₂e/m², representing an approximate 11% reduction compared to timeframe 1.

7. Conclusion

The aim of this study was to deepen the understanding of sustainable heritage practice in the Netherlands by evaluating the impact of energy reduction measures on heritage values, energy performance, and CO₂ emissions.

We found that heritage values—both visual and material—were lost to varying extents across the case studies. For example, the removal of single glazing and the addition of insulation impacted architectural details. In all cases, stakeholders tried to minimise the loss of heritage values by applying reversible energy reduction measures. Consequently, several “lost” heritage values are concealed. In one case, a new living room was created in the barn to avoid damaging high heritage values in the original rooms. In other cases, heritage values had already been compromised due to a poor technical condition, which created opportunities for energy reduction measures. Additionally, some owners noted that restoration activities were inherently sustainable, as they prevented heat loss through cracks, for example.

Energy performance varied significantly across the four case studies. This can partly be attributed to the different energy reduction measures implemented, particularly to the transition from fossil fuels to renewable energy, and, in one case study, to the increased heated volume. On average, energy performance improved with a CO₂ reduction of approximately 52%. This exceeds the 19% of the Dutch Sustainable Heritage Monitor (De Vries & De Jong, 2024), but matches the ambitions set in Dutch Sustainable Heritage Roadmap (Routekaart Duurzaam Erfgoed, 2019)—which are a 40% CO₂ reduction by 2030 and a 60% reduction by 2040. Two of the investigated case studies already achieve the 2040 ambitions, by approximately 62% and 63%. We want to emphasise that the primary focus of the four projects was restoration, with energy reduction ambitions only as secondary objectives.

The CO₂ emissions assessment accounted for both the use stage (operational carbon or energy consumption) and the construction stage (or embodied carbon or removed and added building materials). These measures on average lowered the CO₂ emissions by circa 6%. While examining the four individual case studies, we observed widely different outcomes; three cases showed a reduction in emissions ranging between approximately 0–37%, while one case saw CO₂ emissions increase by approximately 224%. This

particular increase can be attributed to the building's prior low use intensity, minimum reduction in energy consumption, and extensive restoration and modernisation interventions. Overall, the findings indicate that CO₂ emissions are strongly influenced by the following factors:

- *Energy consumption figures:* For three cases (Leens, Appingedam, Spijk), energy consumption constituted a dominant contributor to baseline CO₂ emissions (timeframe 1). Traditionally, the environmental impact of the energy source, such as natural gas or solar energy, played a strong role;
- *Daily use:* All cases exhibited relatively low indoor temperatures, ranging between 16–19°C. Moreover, when the heated surface area and volume of the building increase, the effectiveness of energy reduction measures tended to diminish. This was found in two cases (Musselkanaal, Spijk);
- *Interaction between operational and embodied carbon:* In cases where buildings were only occasionally used during timeframe 1 (and in some instances timeframe 2), the baseline CO₂ emissions were relatively low. As a result, material interventions such as restoration and modernisation could lead to a net increase in CO₂ emissions. This was observed in one case (Musselkanaal). Furthermore, extensive interventions required for maintenance or modernisation also contributed to increased emissions in two cases (Musselkanaal, Appingedam).

Our findings offer added value to the Monitor for Sustainable Heritage (De Vries & De Jong, 2024) by demonstrating how a more holistic approach is crucial for comprehending why specific results for sustainable heritage are achieved (Lidelöw et al., 2019; Webb, 2017; Wise et al., 2021). We recommend expanding the Monitor's survey to include questions on daily use, simultaneous execution of maintenance, modernisation, and energy interventions, and impact of energy reduction measures on heritage values. The latter should be addressed using a consistent and accessible approach, particularly for owners of built heritage who are not trained in heritage value assessment. Therefore, we recommend further developing the approach of Serrano et al. (2022) who distinguish sustainable heritage scenarios, such as the energy-efficient restoration design scenario and the energy renovations design scenario that does not include a heritage valuation.

To close, our study concludes that even when energy reduction ambitions are secondary targets of restoration, good results can be achieved, although it may come at a cost.

Acknowledgments

We would like to express our gratitude to the owners of the heritage buildings for their hospitality in meeting with us multiple times, providing data and other information, and reflecting on preliminary findings of our study. Their cooperation was essential for the successful execution of our research. Additionally, we extend our thanks to the province of Groningen for facilitating access to the owners of the heritage buildings and for sharing important data about the case study buildings with us. We also appreciate the support of various organisations that provided additional data, including the Dutch National Heritage Agency and several municipalities and companies.

To enhance the quality of scientific English in this article, we are grateful to Alex van Spyk for providing valuable feedback. Furthermore, we thank Rikst van der Schoor, who lived several years in the United Kingdom, and improved the quality of scientific English of the final version of this article.

Funding

The research, including data collection and evaluation of the impact of energy reduction measures, was a paid assignment by the Dutch National Heritage Agency for Libau and Hanze. This research was conducted between November 2023 and September 2024.

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Due to the nature of the research, data sharing is not applicable to this article.

LLMs Disclosure

During the writing process, we used the AI language model Copilot from Microsoft to check our concept article for spelling and grammar mistakes. The software operates in a closed environment, ensuring that the input texts are not uploaded to a public database.

References

- Baker, H., Moncaster, A., Remøy, H., & Wilkinson, S. (2021). Retention not demolition: How heritage thinking can inform carbon reduction. *Journal of Architectural Conservation*, 27(3), 176–194. <https://doi.org/10.1080/13556207.2021.1948239>
- Costantino, C., Benedetti, A. C., & Gulli, R. (2024). The role of circular design principles in the language of residential architecture. A reflection on the implications that technical aspects bring to the contemporary way of building. In C. Bartolomei, A. Ippolito, & S. H. T. Vizioli (Eds.), *Contemporary heritage lexicon* (pp. 1–23). Springer. https://doi.org/10.1007/978-3-031-61245-9_1
- De Erfgoedstem. (2014). *Stichting stelt 'menukaart' op voor duurzame monumenten*. <https://erfgoedstem.nl/stichting-de-groene-grachten-zorgt-voor-doorbraak-duurzame-monumenten>
- De Jonge, W. (2011). *Duurzaam verbeterd! Bepaling duurzaamheid herbestemming karakteristieke gebouwen*. Wessel de Jonge Architecten bna BV & Climate Design Consult; Bouwadviesgroep voor bouwfysica.
- De Vries, P., & De Jong, J. H. (2024). *Monitor Routekaart Verduurzaming 2024, week van het duurzame erfgoed 2024* [PowerPoint presentation].
- Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings. (2024). *Official Journal of the European Union*. <https://eur-lex.europa.eu/eli/dir/2024/1275/oj/eng>
- Dişli, G., & Ankaraligil, B. (2023). Circular economy in the heritage conservation sector: An analysis of circularity degree in existing buildings. *Sustainable Energy Technologies and Assessments*, 56, 103126. <https://doi.org/10.1016/j.seta.2023.103126>
- Eerste Kamer der Staten Generaal. (2017). *Goedkeuring Overeenkomst van Parijs betreffende klimaatverandering*. https://www.eerstekamer.nl/wetsvoorstel/34589_goedkeuring_overeenkomst_van
- European Commission. (2019). *Communication from the Commission: The European Green Deal*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640>
- European Environment Agency. (2019). *EMEP/EEA air pollutant emission inventory guidebook 2019*.
- Huuhka, S., & Vestergaard, I. (2020). Building conservation and the circular economy: A theoretical consideration. *Journal of Cultural Heritage Management and Sustainable Development*, 10(1), 29–40. <https://doi.org/10.1108/JCHMSD-06-2019-0081>

- I&W. (2024). *Omgevingswet*. Overheid.nl. <https://wetten.overheid.nl/BWBR0037885/2024-01-01#Hoofdstuk23>
- Klimaatakkoord. (2018a). *Hoe het Klimaatakkoord tot stand kwam*. <https://www.klimaatakkoord.nl/organisatie/hoe-het-klimaatakkoord-tot-stand-kwam/sectortafels>
- Klimaatakkoord. (2018b). *Ontwerp van het Klimaatakkoord—hoofdstuk Gebouwde omgeving*. <https://www.klimaatakkoord.nl/organisatie/documenten/publicaties/2018/12/21/gebouwde-omgeving>
- Lidelöw, S., Örn, T., Luciani, A., & Rizzo, A. (2019). Energy-efficiency measures for heritage buildings: A literature review. *Sustainable Cities and Society*, 45, 231–242. <https://doi.org/10.1016/j.scs.2018.09.029>
- MESH Energy. (2024). *Mesh_Stage_1_Embodied_Carbon_Calculator_v8_Released_7-6-24*. <https://www.mesh-energy.com/resources/embodied-carbon-calculator-v2>
- Nusselder, E. J., Van de Ven, H., Haas, M., & Dulski, B. (2008). *Handboek Duurzame Monumentenzorg. Theorie en praktijk van duurzaam monumentenbeheer*. Stichting ISSO.
- OCW. (2024). *Erfgoedwet*. Overheid.nl. <https://wetten.overheid.nl/BWBR0037521/2024-01-01#Hoofdstuk11>
- Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: Measuring innovation in the product chain*. PBL Netherlands Environmental Assessment Agency. <https://library.wur.nl/WebQuery/groenekennis/2200191>
- Provincie Groningen. (2024). *Subsidieregeling groot onderhoud en restauratie rijksmonumenten provincie Groningen 2024*. Overheid.nl. <https://lokaleregelgeving.overheid.nl/CVDR724996/1>
- RCE. (2024). *Eenheid en verscheidenheid (achtergronddocument), een zoektocht naar een integrale cultuurhistorische waardestelling van het materiële erfgoed*. <https://www.cultureelerfgoed.nl/onderwerpen/waarderen-van-cultureel-erfgoed/documenten/publicaties/2014/01/01/eenheid-en-verscheidenheid-achtergronddocument>
- Right Marktonderzoek en Advies. (2022a). *Rapportage monitor verduurzaming monumenten 2021*. Routekaart Verduurzaming Monumenten. https://www.duurzaamerfgoed.nl/sites/default/files/2022-02/2021_Rapportage%20monitor%20verduurzaming%20monumenten_0.pdf
- Right Marktonderzoek en Advies. (2022b). *Rapportage monitor verduurzaming monumenten 2022*. Routekaart Verduurzaming Monumenten. https://www.duurzaamerfgoed.nl/sites/default/files/2022-11/2022_Rapportage%20monitor%20verduurzaming%20monumenten.pdf
- Right Marktonderzoek en Advies. (2024). *Rapportage monitor verduurzaming monumenten 2023*. Routekaart Verduurzaming Monumenten. https://www.duurzaamerfgoed.nl/sites/default/files/2024-09/2023_Rapportage%20monitor%20verduurzaming%20monumenten.pdf
- Right Marktonderzoek en Advies. (2025). *Rapportage monitor verduurzaming monumenten 2024*. Routekaart Verduurzaming Monumenten.
- Routekaart Duurzaam Erfgoed. (2019). *Routekaart verduurzaming monumenten*. <https://www.duurzaamerfgoed.nl/sites/default/files/2020-06/2019%20Routekaart%20Verduurzaming%20Monumenten.pdf>
- Routekaart Duurzaam Erfgoed. (2022). *Monitoringrapportage monumenten 2022*. <https://www.duurzaamerfgoed.nl/sites/default/files/2022-11/29092022%20monitoringsrapportage%20monumenten%20def.pdf>
- Sekuur, M. (2024). *Foto's behorend bij de Evaluatie verduurzaming Rijksmonumenten Groningen (Libau 2024)*. Rijksdienst voor het Cultureel Erfgoed.
- Serrano, T., Kampmann, T., & Ryberg, M. W. (2022). Comparative life-cycle assessment of restoration and

- renovation of a traditional Danish farmer house. *Building and Environment*, 219, 109174. <https://doi.org/10.1016/j.buildenv.2022.109174>
- Stichting ERM. (2019). *Restauratieladder als leidraad*. <https://www.stichtingerm.nl/restauratieladder>
- Stichting ERM. (2020). *Uitvoeringsrichtlijn 2001, Bouwkundig advies monumenten*.
- Stichting ERM. (2024). *Uitvoeringsrichtlijn 2007 Bouwhistorisch Onderzoek met waardenstelling*.
- Stichting Nederlandse Milieudatabase. (n.d.). *De Nationale Milieudatabase*. <https://milieudatabase.nl/en/database>
- Stichting NEN. (2012). *NEN-EN 15978:2011—Duurzaamheid van constructies—Beoordeling van milieuprestaties van gebouwen—Rekenmethode*.
- Stichting NEN. (2017). *NEN-EN 16883:2017 [Behoud van cultureel erfgoed—Richtlijnen voor verbetering van de energieprestatie van historische gebouwen]*.
- United Nations. (2015). *Adoption of the Paris Agreement*. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
- Van der Schoor, T. (2020). *Strategies for energy reconfigurations: Obduracy, values and scripts* [Unpublished doctoral dissertation]. Maastricht University. <https://doi.org/10.26481/dis.20200528ts>
- Van der Schoor, T., Peine, A., & Van Lente, H. (2024). Contested commensuration: The case of a valuation instrument for historical buildings. *Valuation Studies*, 11(1), 138–161. <https://doi.org/10.3384/VS.2001-5992.2024.11.1.138-161>
- Vieveen, M., Banninga, A., & Munuswamy, T. (2024). *Evaluatie verduurzaming rijksmonumenten Groningen*. Libau. <https://hbo-kennisbank.nl/record/oai:research.hanze.nl:publications/8ce10c1b-ecf9-4dcc-9da3-1074306f7500>
- Webb, A. L. (2017). Energy retrofits in historic and traditional buildings: A review of problems and methods. *Renewable & Sustainable Energy Reviews*, 77, 748–759. <https://doi.org/10.1016/j.rser.2017.01.145>
- Wise, F., Moncaster, A., & Jones, D. (2021). Rethinking retrofit of residential heritage buildings. *Buildings & Cities*, 2(1), 495. <https://doi.org/10.5334/bc.94>
- Yang, Q. Z., Zhou, J., & Xu, K. (2014). A 3R implementation framework to enable circular consumption in community. *International Journal of Environmental Science and Development*, 5(2), 217–222. <https://doi.org/10.7763/IJESD.2014.V5.481>
- Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Sage.

About the Authors



Maarten Vieveen is a researcher in sustainable heritage, with a background in building engineering and spatial planning. He has been involved in studies on energy reduction measures in built and landscape heritage, users' valuation of heritage, climate change impacts on heritage, and digital innovation for heritage practices.



Aron Banninga is an architecture and urban planning historian, heritage advisor, and secretary of the Integrated Committee for Spatial Quality and Heritage. In previous roles, he worked as an energy performance advisor, implemented a maintenance monitor for heritage buildings, and established a sustainable heritage department at a building engineering firm.



Tamizhselvan Munuswamy is a mechanical engineer and an expert in energy systems. As coordinator and instructor for the Project Energy Systems, he leads a team that annually guides approximately 30 students in conducting energy performance assessments on various heritage buildings, in collaboration with their owners.



Tineke van der Schoor is a social scientist leading a research line on sustainable heritage, encompassing sustainability, climate change, valuation, and digitalisation. In 2020 she completed her PhD dissertation “Strategies for Energy Reconfigurations: Obduracy, values and scripts,” focussing on local energy communities and sustainable heritage.

Zero-Emission and Zero Demolition: Promoting Conservation Interests Through the Implementation of the Energy Performance of Buildings Directive

Anna Donarelli

Department of Archaeology, Ancient History and Conservation, Uppsala University, Sweden

Correspondence: Anna Donarelli (anna.donarelli@uu.se)

Submitted: 30 April 2025 **Accepted:** 10 September 2025 **Published:** 19 November 2025

Issue: This article is part of the issue “Aligning Heritage Conservation and Climate Mitigation Through Adaptive Reuse” edited by Liam James Heaphy (University of Galway) and Philip Crowe (University College Dublin), fully open access at <https://doi.org/10.17645/up.i461>

Abstract

To achieve “zero-emission” in buildings, “zero demolition”—keeping existing buildings in use—could be promoted to a greater extent. Continuous use can even prove to be beneficial for climate mitigation as well as for conservation of heritage values in the building stock. The Energy Performance of Buildings Directive (EPBD) has been revised and entered into force in the EU in May 2024. It gives member states the opportunity to adapt several central concepts, with the ultimate objective of achieving a decarbonised building stock by 2050. This study shows how conservation interests are conveyed and taken into account in the earliest stages of the EPBD implementation by two Swedish authorities with responsibility for heritage and built environment. The study aims to identify challenges and opportunities for aligning the implementation with conservation interests. Data have been collected through interviews with involved officials. An agnostic perspective is applied in the analysis, rejecting presumptions of conservation practices being intrinsically sustainable but highlighting the practices’ potential to contribute to sustainability. The new EPBD allows for national implementation in line with conservation interests, which include exemption from energy requirements for heritage buildings and promotion of circularity. Results from this study show that the two authorities focus on the exemption as the main conservation interest, but in the discussions between them other interests are taken into account. The results aim to support clearer statements from the conservation sector and increased relevance, not only in this context but in others where climate mitigation is the objective as well.

Keywords

building conservation; Energy Performance of Buildings Directive; heritage values; historic buildings; sustainable renovation; zero-emission buildings

1. Introduction

With the aim of reaching “zero-emission” in buildings, “zero demolition”—the continued use of existing buildings—could be promoted to a greater extent. In the context of the preparatory work being done for Sweden’s implementation of the new Energy Performance of Buildings Directive (EPBD), this study aims to provide an improved knowledge base on conservation interests and the possibilities to align them with the targets of the Directive. In Sweden, preparations for implementing the revised EPBD that entered into force in May 2024 are underway (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024). The Swedish National Board of Housing, Building and Planning (Boverket, henceforth BV) has several government mandates linked to the implementation of the Directive. Some of them include conducting a dialogue with the Swedish National Heritage Board (Riksantikvarieämbetet, henceforth RAA). Specifically, RAA is to submit views on suggestions regarding “buildings formally protected as part of a designated environment or because of their special architectural or historic merit, or other heritage buildings” (Regeringen, 2024, p. 2).

The purpose of the present study is to show how the interests of conservation are conveyed, handled, and given meaning in a specific process of implementing new policy on renovation. It is limited to the preparatory work that took place between June 2024 and March 2025 on the government mandate to establish methodologies and definitions (Regeringen, 2024). During this critical process of determining directions for future implementation, the discussions between the involved agencies have been followed. So far, the outcomes from BV are two published interim reports with suggestions for definitions of central concepts and possible changes required in current legislation (BV, 2024, 2025c). In the following steps of the implementation, the suggestions from this first stage will be considered and possibly revised, based on a consultation process and political decisions. These following stages of the process are not part of the present study. The final national implementation of the EPBD will take effect in May 2026 (BV, 2025a).

1.1. Previous Research

As a field, building conservation involves preserving and using built heritage. It includes policy development, planning, selection, documentation, and on-site conservation and restoration of buildings. As an academic subject, it is interdisciplinary, encompassing knowledge from both the humanities and technical domains. Energy renovation and building conservation have been perceived as conflicting interests since the 1970s. Legnér and Leijonhufvud (2019) conclude, in a study on heritage values in previous energy policies, that the relationship between these issues has changed since the 1970s, in terms of how energy efficiency requirements are no longer about saving oil nationally but about a global concern for climate change, and what is treated as heritage has expanded. The renovations from the oil crisis are now considered to have distorted heritage values, as they resulted in thick additional insulation, reduced window areas, and the addition of modern materials to traditional buildings. They have been considered unsuitable renovations from a technical perspective as well. In Sweden, these renovations were subsidised by the government, today seen as an example of poor policy implementation. Although the climate crisis has increased the urgency of the matter, and there is consensus that the 1970s renovations created deterrent examples, the perception of conflict between heritage values and energy saving remains among experts in the conservation field (Legnér & Leijonhufvud, 2019). The concern is mainly with heritage values connected to materials and aesthetics, often only the exterior character-defining elements. This concern is applied to large

parts of the building stock, not only monuments or listed buildings. The aim in previous research has been to find ways of improving energy efficiency without damaging heritage values by finding a balance between different demands (Eriksson, 2021). Since the early 2000s, starting in the UK, energy efficiency in historic buildings and sustainable heritage have been researched as part of the conservation sector's engagement in climate issues (Barthel-Bouchier, 2015; Cassar, 2009). It has been shown in research that energy saving and conservation of heritage values can be combined. Aspects of life cycle assessments (LCAs) that link to circularity and the continued use of buildings, which contribute to lower climate impact than demolition and new construction, have been incorporated to promote a more holistic view on energy use (Lidelöw et al., 2019; Martínez-Molina et al., 2016; Webb, 2017). Some researchers have identified a need for clearer guidance on the implementation of existing legislation on heritage values in the Swedish building stock in light of new energy demands (Christiernsson et al., 2021; Geijer et al., 2022; Hagelqvist et al., 2024).

Different conservation perspectives coexist and can, in practice, both limit and promote climate mitigation. Avrami (2016) finds that many heritage authorities argue that heritage buildings are intrinsically sustainable, yet they maintain that these buildings need exemption from energy requirements. Like other claims on conservation practice and heritage assets as inherently sustainable, they appear contradictory and are not based on data and research. Such stands lead to conflicts and misunderstandings. Avrami concludes that in order for the conservation sector to actually contribute to a sustainable society, it is necessary to understand and confront these contradictions. Pendlebury (2009) notes that conservation policy today protects both the ordinary and the special, the monumental and the mundane, including buildings from the relatively recent past. At the same time, conservation's basic principle of "minimum intervention" has not changed, although the number of buildings for which conservation principles are applied has increased through new planning and building regulations (Pendlebury, 2009). The Swedish planning and building regulations show a similar development, described by Geijer et al. (2022). Reactions against industrially produced new constructions, increased demolitions, and incautious renovations led to new legislation in the 1980s. This legislation, still in use today, aimed to protect heritage values in everyday environments which had previously not been the object of conservation practices (Geijer et al., 2022).

Huuhka and Vestergaard (2020) argue that, in the context of renovation, minimum intervention and climate mitigation could be aligned, but formal protection might prove to be an obstacle in this alignment. The authors state that listing and arguing for preserving certain selected objects leads to the construction of non-heritage, where everything that is not selected has no value. They invite the conservation discipline to look beyond their current value-centred approaches rooted in the linear economy by expanding their concept of values and embracing true circularity. This will, the authors state, lead to the conservation of more built heritage, as well as minimise climate impact from the building sector. Baker et al. (2021) show how in decision-making where the options are demolition or preservation, the environmental impact is rarely the main reason for choosing retention, instead heritage policy plays an important role. The researchers found that regulations today protect buildings with heritage values from demolition, but not buildings with embodied carbon value, which points to a need for new policy. Yarrow (2019) looks into how increased efforts to save energy and renovate with environmental concerns in mind make buildings matter in new or different ways. Yarrow's study on homeowners' renovations "highlights how conservation is made to matter through practices of renovation, in the linked but distinct senses of having value and importance, and of taking material form" (Yarrow, 2019, p. 18).

1.2. Positioning

In the Swedish context, previous research has assessed specific aspects of legal implementation relating to energy saving and conservation (Christiernsson et al., 2021; Geijer et al., 2022; Hagelqvist et al., 2024) and evaluated former policy implementation (Legnér & Leijonhufvud, 2019; Legnér et al., 2020). This study aims to provide new perspectives, in which climate change mitigation and the conservation of buildings are not seen as conflicting interests that need to be balanced, but rather that the interests of conservation and the need for climate action can be aligned. Not only do different disciplines coexist within the field of conservation, but there are also different, sometimes conflicting, perspectives. Brumann (2014) identifies approaches within the heritage field that he calls “heritage belief” and “heritage atheism.” Heritage belief is based on the notion that heritage in and of itself is a good thing, with intrinsic values that automatically contribute to society. With this perspective, conservation for conservation’s sake is endorsed. Heritage atheism, on the other hand, does not see heritage and the preservation of it as naturally positive, but something that in practice serves more undesirable purposes than what is generally perceived or openly disclosed. This is mostly a vision of heritage scholars, who point out how heritage is created in the present based on different agendas, that it fails to represent diverse histories, groups, and cultures, and that it suppresses creative change. Brumann (2014) encourages instead “heritage agnosticism” as a way for reaching better alignment of theory and practice. The agnostic approach acknowledges the social construction of heritage and its related practices. It does not see heritage value as intrinsic, but still takes people’s heritage experience seriously and accepts that some qualities used for ascribing heritage value may be connected to the history and materiality of objects. With this approach, determining conservation practice’s positive or negative impacts on society requires empirical investigation, without a presumption of it being “good” or “bad” (Brumann, 2014). This present study is inspired by the agnostic approach and analyses a specific context of conservation practice, namely its efforts and narratives related to minimising the climate impact of buildings.

1.3. Aim and Problem Statement

This study covers the initial part of policy development, namely the preparations for the implementation of the EPBD. At this early stage, visions of aspired to outcomes guide decisions. The perspectives these visions represent can show differences in priorities related to minimising the climate impact of buildings. Such differences influence decision-making and can create both challenges and opportunities. It is a unique study of current policy development and is relevant to all EU member states.

The aim is to identify challenges and opportunities for aligning the implementation of the EPBD with conservation interests and provide insights that can be used to advise the subsequent steps of policy development. The possibilities of the EPBD to promote conservation interests are investigated by identifying the efforts and narratives related to the conservation and the climate impact of buildings.

2. Conservation Interests and the EPBD

The new EPBD aims to achieve a fully decarbonised building stock in the EU by 2050, and introduces new concepts and policy instruments for member states to interpret and implement on a national level (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024). The main focus is on the renovation of existing buildings. Since 85–90% of existing buildings are expected to remain

until 2050, they need renovation in order to save energy for heating and cooling. But the climate impact of renovation needs to be considered as well (European Commission, 2020). In Sweden in 2022, new construction accounted for 21% of total emissions from the building and property sector, heating accounted for 28%, renovation for 28%, and property management for 24% (BV, 2025d). It is especially relevant for this study to note that heating and renovation have the highest climate impact and have equal impacts. Renovations serve to reduce carbon emissions, but they also produce them. It is necessary to make sure emissions are diminished in both categories. In terms of policy instruments, retroactive demands in the form of minimum energy performance standards (MEPS) for non-residential buildings, aimed to force the renovation of the worst-performing buildings, are new to the Directive. So are binding targets for diminishing the average energy performance of the residential building stock. Diminishing emissions from buildings, rather than just improving energy performance, is emphasised more in the new EPBD compared to the previous one (Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, 2010; Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024).

Conservation interests are only explicit in the Directive as possible reasons for exemptions from energy requirements (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024, Articles 5:2 and 9:6a). With the previous Directive, member states could decide not to set or apply energy requirements for “buildings officially protected as part of a designated environment or because of their special architectural or historical merit, in so far as compliance with certain minimum energy performance requirements would unacceptably alter their character or appearance” (Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, 2010, Article 4:2a). At that time, Sweden chose not to officially exempt protected buildings but instead allowed for adapted requirements on energy saving in the building regulations (Geijer et al., 2022). Keeping and expanding the possibility to exempt historic buildings was called for by heritage organisations throughout the EU in responses to draft versions of the revised EPBD in 2021. Initially, only officially protected buildings were included for possible exemptions or adapted requirements, and it was emphasised that not all buildings with historic and local significance are officially protected. It was also stressed that buildings with heritage values can become more energy efficient, but that it is necessary to correctly assess their performance and to apply balanced and flexible approaches to the requirements (Directorate-General for Education, Youth, Sport and Culture, 2022; ICOMOS ISCES, 2021). According to the final version of the Directive, member states may adapt minimum energy performance requirements to “buildings officially protected at national, regional or local level, as part of a designated environment or because of their special architectural or historical merit, in so far as compliance with certain requirements would unacceptably alter their character or appearance” (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024, Article 5:2). They may decide not to apply MEPS and its trajectories to “buildings officially protected as part of a designated environment or because of their special architectural or historical merit, or other heritage buildings” (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024, Article 9:6a) to avoid alterations of character and appearance, and also “if their renovation is not technically or economically feasible” (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024, Article 9:6a).

In Sweden, heritage buildings referred to in these paragraphs of the EPBD would be those protected by the Historic Environment Act (HEA) or the Planning and Building Act (PBA). The HEA protects buildings through listing (Sveriges Riksdag, 1988). In 2021, there were 2,270 privately owned and 286 state-owned listed built

environments in Sweden. Most of these sites contain more than one building and other kinds of built structures (Myndigheten för Kulturanalys, 2022); in total, there are about 11,000 listed individual objects in the registry (RAA, 2025). State-owned listed buildings are managed at the national level by RAA, and the privately-owned are managed at the regional level by the County Boards. This management involves the selection of the buildings, description of their heritage values, and the permitting for alterations (Myndigheten för Kulturanalys, 2022). Protection of heritage values according to the PBA is managed at the municipal level in the building permits for alterations and the zoning plan processes. The PBA provides two forms of protection for buildings and built environments: the requirement of caution and the prohibition of distortion. The requirement of caution applies to all existing buildings and requires all changes to be made “taking into account the characteristics of the building and recognising its technical, historical, cultural, environmental and artistic values” (Sveriges Riksdag, 2010, Chapter 8:17). The prohibition of distortion applies to particularly valuable buildings or built environments (Sveriges Riksdag, 2010, Chapter 8:13) and requires that heritage value be assessed based on aspects such as how the building represents past living conditions, architectural ideals, societal values, or important local functions. A building can be identified as particularly valuable during the processing of a building permit application, and a permit can be denied based on this prohibition even if the building had not been previously identified as such (BV, 2025b). Both the requirement of caution and the prohibition of distortion potentially protect heritage values in all existing buildings, but the processes connected to the PBA involve making expert assessments of what these values are and how the suggested alterations affect them on a case-by-case basis.

In the responses from heritage organisations to draft versions of the EPBD, circularity and life cycle perspectives were highlighted as beneficial for the preservation of heritage values in the building stock, as well as for climate mitigation. It is stated that historic buildings should be considered “resources” because of their long lifetime and their stored energy and carbon. Conservation practice should also be considered environmentally sustainable because the reuse and continuous repair of existing buildings and building elements are effective ways to minimise greenhouse gas emissions (Directorate-General for Education, Youth, Sport and Culture, 2022; ICOMOS ISCES, 2021; Potts, 2022). Research comparing the environmental impact of demolition and new construction with the preservation of existing buildings shows that preservation, generally, results in a lower impact (Berg & Fuglseth, 2018; Janson et al., 2022; Röck et al., 2020). However, there are several other choices between these two extremes that will be made during the course of any building’s lifetime, connected to renovation and maintenance, that have different impacts. The studies also show how unknown future scenarios, such as the development of the energy system, make the results of LCAs very variable (Janson et al., 2022), and that there is little transparency and comparability in studies on embodied climate impact (Röck et al., 2020). The new EPBD allows for the consideration of life cycle perspectives and the climate impact of renovation, but requires the calculation of the global warming potential (GWP) only for new construction (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024). Currently, in Sweden, the use of assessments of climate or environmental impact applies only to new construction, not to renovations.

3. Data and Method

Using a participatory method, data have been collected through semi-structured interviews with the officials directly involved in working with the EPBD implementation (three from RAA and two from BV; see Table 1). All except one interviewee have worked for several years with energy efficiency in buildings, being involved

in activities regarding the previous version of the EPBD as well. Questions covered the interpretation of the EPBD and government mandates, perceived risks, desired outcomes, views on minimising the climate impact of the building sector, and the potential for promoting circularity. The interviews lasted between one and one and a half hours. Quotes from the interviews are referred to with ID codes. Providing complete anonymity for professionals employed at public agencies and assigned specific mandates is, however, not possible. This limited anonymity was discussed with the participants, and they all gave their consent to participate with that in mind. Unpublished documents, including a project plan and three internal communications regarding priorities in the field of heritage values in municipal planning and climate adaptation and mitigation, were shared by RAA officials after the interviews and integrated into the dataset. As part of the government mandate, BV published one report in October 2024 and one in February 2025, in which it suggests ways forward (BV, 2024, 2025c). The written feedback to these reports, provided by RAA before their publication, was used in the analysis. Adding these written unpublished sources to the dataset served to verify the different perspectives of the agencies. Participation in two meetings organised by RAA with the purpose of discussing the consideration of conservation interests with participants from BV and the Swedish Research Institute helped to form an understanding of how the officials confer with each other. The data from these meetings were not coded for the analysis. Overall, this qualitative dataset forms a large, but not complete, picture of the discussions around the initial work with the EPBD implementation.

Table 1. Participants in interviews.

ID	Background/Title
IntRAA1	Architect/Adviser
IntRAA2	Conservation officer/Adviser
IntRAA3	Conservation officer/Adviser
IntBV1	National economist/Economist
IntBV2	Physicist/Project leader

Interviews have been transcribed verbatim. The transcripts and unpublished documents have been imported into a qualitative data analysis tool, NVivo 1.6, and analysed using thematic analysis (Braun & Clarke, 2022). The data were coded with an inductive, data-driven approach, in several steps. The themes were developed based on identified patterns that were considered meaningful for answering the research questions. The final themes are shown in Table 2. Thematic analysis is a subjective practice, and the process of coding and analysing data has involved continuous reflection on this subjectivity. Several systematic iterations of creating codes and themes occurred during the course of the analysis, in order to represent the meaning of the data. The final result is a description and an interpretation of the data, based on the data themselves (Braun & Clarke, 2022).

An agnostic perspective has influenced and guided the analysis (Brumann, 2014). Applying this perspective is not aimed at criticising, but at challenging accepted truths that might need to be re-evaluated in light of the climate crisis. In the context of this study, the agnostic perspective is used to identify ideas to challenge and assumptions to verify using increased knowledge. Further, the perspective helps to find and highlight the potentials of conservation practice.

Table 2. Themes used in the analysis.

Theme	Sub-theme	Meaning
Perceived risks	Lack of preparedness	The perception that there is a lack of awareness and preparedness among those who are to apply new regulations.
	Physical changes to the built environment	Risks involving physical changes in the building stock, which may lead to undesirable consequences.
Aspired outcomes	Increased awareness	New rules could lead to increased awareness about sustainable renovation and conservation.
	Conservation could lead the way	Conservation knowledge could inform the building sector in mitigation strategies.
Using the EPBD	Exemptions	Interpretations of the exemption for buildings with heritage values, and ideas about its implementation.
	Zero-emission building	Interpretations of the zero-emission building target, and ideas about its implementation.
	Circularity	Interpretations of the possibility of promoting circularity, and ideas about its implementation.

4. Results and Analysis

This section is based on data from the interviews and unpublished documents. It starts with a description and analysis of the agencies' perceptions of risks and aspired outcomes, then continues describing and analysing how the EPBD, at this early stage of the process, is interpreted and planned to be implemented. Quotes from the interviews are used throughout the text to present and analyse the different themes.

4.1. Perceived Risks

There may be risks involved in implementing new requirements, and different aspects connected to both legislation and practice need to be reinterpreted in a new context. In the interviews, the respondents were asked to express thoughts on challenges, opportunities, possible conflicts of interest, and expected changes in handling energy use and heritage values. These ideas are also expressed in published and unpublished documents.

4.1.1. Lack of Preparedness

RAA officials express fears about the municipalities not being ready to weigh the importance of different demands as more are added:

It becomes problematic when something like this [EPBD] with such major consequences is to be implemented in a fairly short time. There is a risk that the result will not be well thought out and sufficiently processed. That the consequences will not be sufficiently clear. I feel that is concerning. (IntRAA3)

An overview of heritage values in the building stock and competence in conservation at the municipalities, where most decisions on changes in existing buildings are taken, is thought to be lacking. These observations

are related to earlier reports from RAA regarding how municipalities often fail to take heritage values into account in accordance with the PBA (RAA, 2017, 2018). There is also a concern that there is a lack of knowledge among energy consultants on which energy saving measures take heritage values into consideration. BV officials also express that there is a need to increase knowledge about the application of heritage protection in municipalities in light of new regulations. BV argued, in response to an earlier version of the EPBD, for amendments that would provide opportunities to continue using the requirement of caution and the prohibition of distortion in the PBA (BV, 2022).

4.1.2. Physical Changes to the Built Environment

If existing buildings cannot fulfil the energy requirements for technical or economic reasons, they could be demolished instead. This was stated in the BV interviews to be highly undesirable because replacing an existing building with a new one can be a major source of greenhouse gas emissions. BV has endorsed the possibility of exempting buildings from the highest energy requirements in situations where lower emissions from a life cycle perspective could be achieved with a lower degree of renovation. There was, and the interviews show there still is, a concern that the EPBD could lead to renovations that have negative climate impacts (BV, 2022).

In an internal communication on priorities in the field of heritage values in municipal planning from RAA, it is stated that the energy transition can be a risk for heritage values because it leads to changes in the built environment. At the same time, the text continues, this transition can provide an opportunity for the historic environment to be used as a resource for the sustainable development of society and for the conservation sector to have an impact. It is stated that reuse today only focuses on frames and building materials, a kind of reuse that requires partial demolition. RAA has identified a need to develop and publish arguments for reuse as on-site repurposing, and examples of heritage values and circularity. This is where the agency sees the potential to make a societal impact and promote sustainable renovation practices.

Huuhka and Vestergaard (2020) provide a theoretical consideration that relates to these aspects expressed by RAA. In a circular economy, conservation would be the conventional way of building, as it would always be a practice based on what already exists. According to Huuhka and Vestergaard, the conservation sector needs to challenge its reluctance towards partial reuse and the relocation of building elements. According to the authors, the linear economy of today limits how conservation is defined and understood—as a practice that is value-oriented towards a small portion of the building stock. Instead, the authors invite reflection on what there is to gain from a truly circular building sector.

Apart from demolition, the risks involving physical changes are mostly implicitly described by respondents in the interviews. It is formulated in the EPBD that energy saving measures may “unacceptably alter [buildings] character or appearance” (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024, 2024, Articles 5:2 and 9:6a). In an interview it was stated that the worry is that there will be “standardised renovations” with additional insulation and replaced windows using “modern materials,” and the current situation was compared to the energy renovations of the 1970s (IntRAA2).

4.2. Aspired To Outcomes

Ideas about aspired to outcomes guide decisions at this preparatory stage of the implementation. These ideas were expressed in interviews and found in documents.

4.2.1. Increased Awareness

BV officials are hopeful that an increased awareness and a broader perspective on energy efficiency and climate mitigation will be the end result of the implementation of the EPBD, both through guidance and regulations:

I think that if we succeed in the way I hope we will, we can increase awareness and focus on preserving what needs to be preserved for various reasons and utilise what exists....Above all, I think it's very important that we focus on not causing unnecessary demolitions or unnecessary renovations that are carbon-driving or harmful in any way. (IntBV2)

IntBV1 expresses that the general issue of minimising climate impact from buildings has become prioritised lately at the agency on account of the EPBD implementation. It is stated by the RAA officials in interviews that the lack of awareness of heritage values will need to be dealt with when developing guidance to municipalities based on the coming energy regulations. RAA officials hope that documentation on heritage values in the building stock could be improved through the agency's involvement in the implementation of the EPBD, as their current work highlights the lack of information they have identified in various other contexts. They express that it has recently become prioritised at the agency to work with guidance on the identification, registration, and protection of heritage values in the building stock. One important reason for this is the fast transition and developments in society towards climate neutrality that, in turn, require changes in landscapes and the built environment.

4.2.2. Conservation Could Lead the Way

In interviews, RAA officials have emphasised that buildings with heritage values could be considered more sustainable if the EPBD is implemented correctly. In this context, the statements relate mainly to listed buildings and those considered particularly valuable according to the PBA. In relation to the EU regulation on sustainable investments (Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020, 2020), listed buildings could be considered automatically sustainable, because “they provide social values” (IntRAA1). LCAs, rather than energy performance, could also prove that “older buildings” are intrinsically sustainable from a climate perspective, because “their emissions have already been paid off” (IntRAA1). It would also be beneficial if economic incentives were directed at heritage buildings or specifically for energy-saving measures that are cautious, in the sense that they take the existing visual and material characteristics of a building into consideration (IntRAA3). Conservation and such cautious approaches to energy saving could set examples for the entire existing building stock (IntRAA2), and traditional passive technologies could be reinstated and used in new construction as well (IntRAA1):

For us, it has been a given in building care to reuse, to preserve and care for, maintain, and manage what exists. Often using good materials that have a longer life than one thinks. (IntRAA3)

Through the implementation of the EPBD, RAA officials say that traditional building techniques can be used to demonstrate how repair of building elements instead of replacement is possible. The importance of using materials with long lives that are maintainable both in renovation and new construction is another issue raised by RAA. There are statements here that identify potentials of conservation practice to contribute to minimised climate impact, but that need to be developed further and verified in order to be useful in the implementation process. It is necessary to recognise and reject misunderstandings, contradictions, and generalisations in order to create solid and relevant evidence.

4.3. Using the EPBD

With the desired outcomes in mind, both agencies have organised their respective work with this mandate. Discussions have concerned the heritage exemption, the definition of the concept of zero-emission building (ZEB), and the overarching aim of decreased greenhouse gas emissions in the building stock. According to the mandate, BV is to interpret the formulations in the EPBD and suggest how these can be defined in a Swedish context. At this early stage, BV provides a preliminary analysis of how current national policy and legislation may need to change and different possible options for methodologies and definitions. BV officials state in interviews that the work with the EPBD implementation could be coordinated with other work at the agency, such as climate declarations and mandates on circular economy, but currently it is not.

RAA officials expressed hopes that the implementation of the EPBD will lead to increased registration of heritage values in the building stock. The agency coordinates the work on the EPBD with other initiatives and priorities within the organisation and with other collaborations they have with BV relating to the built environment. At this early stage of the implementation, RAA has a clearer view than BV on what they find necessary after the implementation, in terms of information to target groups. RAA is not officially involved in the new mandates BV has received from the government. Both agencies intend for RAA to be involved to some extent, through the agencies' other collaborations concerning the development of the built environment.

4.3.1. Exemptions Should Be Avoided

The main focus in discussions between the agencies is on the possibilities for exemptions. The official standpoint of RAA is that even listed buildings should be improved in terms of energy efficiency:

I interpret that the exemption nowadays is to impose adapted requirements. Which is much more...not favourable...but more appropriate than just exempting these types of buildings. Because then they would be treated as something inferior or that they don't have the ability to meet modern requirements. And we know that's not true. (IntRAA1)

In interviews with RAA representatives, the new EPBD is described as "sharper" compared to the old one, because the exemption is not really an exemption, and the requirements go further by including retroactive energy requirements in existing buildings. They state there is disagreement within the agency on whether or not this is a problem, but the official statement is that exemptions should not be applied. In the new EPBD, buildings officially protected at the national, regional, or local level (Directive 2024/1275, Article 5§2) are mentioned as possibly qualifying for exemption, along with other heritage buildings as well. Exemptions can also be applied if a renovation is not technically or economically feasible (Directive 2024/1275, Article 9§6a).

These new formulations imply an expansion of what kind of official heritage protection may count, as well as a possibility to exempt heritage buildings without official protection. Measures can be deemed unsuitable based not only on their impact on character and appearance but also feasibility. Rather than being stricter than the former version, it could be argued that the new EPBD is more in line with the current national implementation as well as with conservation interests. The interpretation of the representatives from both agencies is that the current legislation on protection of heritage values will still be applicable, both HEA and PBA. Therefore, it is concluded that exemptions are not necessary, but clearer guidance is required. One important reason for RAA to endorse the inclusion of buildings with heritage values in the coming policy implementation is to not exclude them from grants that might be made available for renovations. BV strives to establish central definitions that take into account the feasibility of measures, and thereby exclude measures rather than buildings:

[Exemptions] can become complicated and complex. It is better to write the rules in a way that makes them achievable and as precise as possible. It is only when the requirement is not entirely accurate that there is a need to make exemptions. So, in order to keep the rules relatively simple, we believe that we should include every building. (IntBV2)

RAA writes in a project plan for the EPBD implementation that they intend to improve the knowledge about heritage values in the building stock. The agency involved researchers at the Research Institutes of Sweden to investigate existing building data and relate them to energy requirements. The result includes a list of officially protected non-residential buildings, including all those protected by the HEA and those registered locally as protected in zoning plans. Local listings are not fully covered, and the researchers experimented with a method using artificial intelligence, combining large language models and decision-tree machine learning, to find aspects of heritage values in the rest of the building stock. The researchers concluded that the artificial intelligence method requires further studies. With a goal of avoiding exemptions, RAA's focus on identifying buildings for which adapted requirements should be established can seem futile. It is still unclear, however, what will be required for the coming mandates. For exemption from and calculation of MEPS, a description of which buildings are exempted might be necessary, according to BV. At this point in the implementation, concerning preliminary methods and definitions, information on heritage values in the building stock has not been used.

4.3.2. Defining ZEBs

Although the initial focus in the discussions between RAA and BV was on exemptions or adapted requirements, the final result is a suggestion on the definition of ZEB. BV interprets the EPBD as allowing a relatively large amount of flexibility in how the limits for energy performance can be established, which they state should be used to achieve the most realistic and balanced levels possible:

What are we actually supposed to achieve by 2050? We have the concept of zero-emission buildings, which is central to the Directive. It actually says that we should achieve a building stock with zero-emission buildings. So, we still need to discuss exactly how we should calculate this. (IntBV2)

The suggestion is that specific levels will be set for different categories of existing buildings, but that it will also be possible to define an existing building as a ZEB "if it can be demonstrated that there are no other profitable measures that are feasible, provided that the other criteria for a zero-emission building are also

met” (BV, 2025c, p. 65). The definition is similar to Herrera-Avellanosa et al.’s (2019) suggestion for a definition of “lowest possible energy demand” in historic buildings. A building’s heritage value does not determine its ability to save energy; instead, factors such as technical status and construction will. The authors suggest an approach applicable to any building, where energy-saving measures are negotiated between stakeholders based on heritage value and other factors. When all measures deemed compatible are implemented, the building has reached its lowest possible energy demand and thus the requirement has been met (Herrera-Avellanosa et al., 2019).

BV finds that this definition will be able to take each specific building’s conditions into account. The heritage values, whether officially protected or not, would then be part of any building’s condition, along with aspects such as technical circumstances, construction techniques, and renovation needs. What these conditions entail in terms of possible measures will be determined during the process of change. It is assumed that this approach could take into account the future development of the energy system and technologies yet to be invented, which cannot be predicted but will affect the possibilities for achieving a ZEB stock (BV, 2025c).

4.3.3. Circularity Can Be Promoted

RAA officials discuss finding other ways to calculate climate impact, which include the whole life cycle of buildings and not only the energy use:

If you could get calculations based on a life cycle perspective more, then you would, for example, have fewer demolitions, I guess, greater circularity. Like reuse, recycling, and material recovery. (IntRAA2)

Life cycle perspectives are mentioned more in the new EPBD compared to the previous version, providing new opportunities beyond assessing merely kilowatt-hours per square metre. Ideas are expressed in interviews with RAA officials that by promoting this kind of calculation, “old buildings” would be able to meet requirements, because their embedded carbon would show they have a minimal climate impact. Existing or “older buildings,” they state, contribute to climate mitigation by having been in use for a long time. This statement demonstrates a misunderstanding of buildings’ climate impact. It is true that when comparing different scenarios for renovation or demolition and new construction, the embodied carbon could be part of the assessment as a kind of avoided impact if a building or building elements are kept instead of being discarded and replaced. However, buildings do not contribute to climate mitigation simply by existing, but through choices for renovation and maintenance made today (Avrami, 2016; Berg & Fuglseth, 2018; Huuhka et al., 2023).

BV emphasises in interviews and documents that it is even more important in Sweden to acknowledge the climate impact of renovations, because the use of fossil fuels for heating is less than in Europe as a whole:

When it comes to carbon dioxide or climate, we have climate declarations and so on, where we have led the way, you could say, for the rest of Europe. And there is a fairly clear link in the issues, and Sweden is pushing quite a lot to be able to continue in the direction we have taken. So, it is closely interwoven. (IntBV2)

Building materials used in renovations, however, can be quite harmful to the climate. In an interview, it was stated that an LCA perspective could be applied to the suggested ZEB definition, which will be able to take

into account the remaining lifespan of various building components and installations. Since exchanging new components or installations would neither be cost-optimal nor feasible, such measures would not be endorsed with this definition of ZEB. The agency will need to determine at a later stage whether the desired promotion of circularity will require new regulations or if other policy instruments will suffice (IntBV2).

4.4. *Aligning Objectives With Different Perspectives*

The perceived risks and aspired to outcomes of the respective agencies show differences in their perspectives and mandates. RAA perceives a risk for undesirable visible changes in the building stock. BV sees a risk that the implementation of the EPBD can become counterproductive and will lead to more greenhouse gas emissions. The hopes expressed by RAA are that heritage values in the building stock will be documented to a greater extent and that existing buildings will be treated as resources. Promoting the idea of existing buildings and building elements as resources is something both agencies want, although they base it on different desired outcomes. For RAA, promotion of circularity is more connected to the will to preserve heritage values, and for BV, to the objective of climate mitigation. The objective of minimising greenhouse gas emissions is central to BV but peripheral to RAA.

Differences in the views of the involved agencies appear in the discussions on exemptions or adapted requirements and become evident when discussing how the objectives of the EPBD should be turned into recommendations for the direction of national policy. The divergencies can be related to differences in the knowledge of the officials and in the mandates they have. RAA's idea to not apply a complete exemption can seem ambiguous, since they still find it necessary to improve registries of heritage values in the building stock in order to protect them when new demands need to be met. BV does not want to create a need for exemptions, but aims instead for definitions that are flexible enough to take into account the various conditions of all buildings, amongst which heritage value is one of many. Although based on different objectives, an agreement has been reached on the final suggestions relating to exemptions and the definition of ZEB. The exemption is viewed from two different perspectives, where one strives to point out which buildings to set adapted energy requirements for, and the other focuses on how to exclude measures with undesirable effects in any building. One view is value-oriented and object-focused and would apply to a small portion of the building stock. The other focuses on measures and aims to protect the whole building stock from those measures deemed unsuitable based on assessments of heritage values as well as on other aspects.

5. Discussion

It is noticeable that the focus from RAA's side in working with the EPBD implementation is on the interpretation of the exemption or the possibilities for adapted requirements. Since they do not want to apply the exemption, the agency struggles to determine which buildings to apply adapted energy requirements to. Apart from buildings officially listed nationally, regionally, and locally, "other heritage buildings" can be exempted as well, and it is unclear which buildings these are. The agency's efforts to determine which buildings to set adapted requirements on result in an object-centred, top-down, and value-oriented approach. Huuhka and Vestergaard (2020) define such approaches as being rooted in the linear economy and instead suggest a reflection on the opportunities a promotion of circular practices in the whole building stock could provide. Knowledge about the existing built environment would be crucial in a

circular building industry, and the conservation sector could contribute with new ways of thinking about circularity, life cycle perspective, and zero demolition.

With promotion of circularity in mind, and with the aim of minimising carbon emissions, methods that describe the built environment, rather than assess the heritage values in it, could be developed along with value-based approaches. The value-based approach can be related to the perceived conflict between energy efficiency and heritage values, dating back to the 1970s. This perception of conflict is reflected in the EPBD itself, through the very possibility of exemptions. The notion of threat to heritage values in buildings in light of new energy demands has become a condition under which the conservation sector operates. The government mandate also limits RAA's assignment to submitting views on "buildings formally protected as part of a designated environment or because of their special architectural or historic merit, or other heritage buildings" (Regeringen, 2024, p. 2). This is not surprising, nor can it be criticised; it is in line with what the agency is expected to work with.

Although it is built into RAA's mandate to focus on protection from change, and the practical work so far has focused on determining the specific buildings to protect, the agency shows ambitions beyond that. RAA officials highlight in interviews the opportunities to promote reuse and circularity through the EPBD implementation. The EPBD opens up the application of a more holistic approach to energy use that takes LCAs into consideration, an opportunity that the conservation sector has also called for. These opportunities mostly focus on how protected buildings can contribute to climate mitigation by setting examples of management through continuous use and care. As noted in the analysis, some of the conservation sector's claims connected to buildings' climate impact show misunderstandings and others may need to be verified. RAA officials are not expected to provide concrete suggestions for how to do an LCA; however, increasing awareness in the conservation sector of what such assessments show and the climate impact of the different stages of a building's life span could be strived for. Officials from both agencies talk about treating existing buildings and building elements as resources, but it is only vaguely described what that would mean in practice and how to implement it in policy. Baker et al. (2021) showed that regulations on heritage values had an impact on decisions on demolition or retention, whereas the environmental benefits that were unregulated did not. This is something for the agencies to consider in the coming policy development.

RAA's generalisations concerning the sustainability of conservation practice and historic buildings become problematic when an agnostic approach is used and when conservation is considered an interest while climate mitigation is a necessity. Despite that, BV has taken some of RAA's arguments on LCA into account and turned them into recommendations for the direction of the implementation going forward. The suggested definition of ZEB is the most striking result of these discussions between the two agencies. A building's heritage value does not determine its ability to reach energy requirements; other conditions like technical status, heating system, and building materials will do so to a greater extent. There are many energy-saving measures that will have no impact on visible character-defining elements in buildings. The heritage values will need to be considered as one of many conditions, each of which might be more or less defining, when choosing energy-saving measures.

All conditions considered will need to be determined on a case-by-case basis. The suggested definition of ZEB aims to take this into account. This is an example of where the need for climate mitigation and the interests of conservation seem to be aligned. Despite their differences in aspired outcomes, knowledge, and mandates,

the agencies demonstrate how different perspectives can be understood in a new context and inform each other. Yarrow (2019) presents results on how conservation is made to matter in homeowners' negotiations and decision-making; the results presented here similarly show how conservation is made to matter in a specific process of implementing new policy. Buildings are abstractly discussed in the present study, yet the threatened materiality highlights how they are important, both as heritage and material resources, and the efforts to contribute to climate mitigation provide new ways of reflecting on how to make these values last.

6. Conclusion

The new EPBD provides opportunities for a national implementation in line with conservation interests, which include adapted energy requirements in buildings with heritage values, and a consideration of LCA to promote the continued use of existing buildings. Regulations to support these aspired outcomes will be necessary.

The results highlight a need to raise awareness in the conservation sector about greenhouse gas emissions, LCAs, and circularity. Potentials for conservation perspectives to contribute to climate mitigation in the building sector have been identified, but also ideas to challenge and assumptions to verify. Energy requirements are still perceived as threats to heritage values, and statements on embodied carbon in existing buildings expose misunderstandings. A shift in perspective towards finding opportunities rather than focusing on threats, and clarifications on how existing buildings are resources in the climate transition could contribute to increased relevance of conservation knowledge, in this context as well as in others where climate mitigation is the objective.

At this initial stage of the implementation process, its consequences are still unclear to the interviewees. Instead, ideas are expressed about policy changes to avoid and promote, which highlight different perspectives. Although the agencies show different approaches to climate mitigation, the result of the collaboration is a positive example of how a combination of different knowledges, mandates, and objectives can create new ways forward in the climate transition. Work at the agencies continues and will result in concrete actions. Further studies on the nexus between conservation and climate mitigation could address the identified knowledge gaps and evaluate forthcoming stages of the EPBD implementation and their effects.

Funding

This research was financed by Formas, the Swedish Research Council for Sustainable Development, within the research school Adaptation of Urban Space Through Sustainable Regeneration (ASSURE). Publication of this article in open access was made possible through the institutional membership agreement between Uppsala University and Cogitatio Press.

Conflict of Interests

The author has previously been employed at the Swedish National Heritage Board.

References

Avrami, E. (2016). Making historic preservation sustainable. *Journal of the American Planning Association*, 82(2), 104–112. <https://doi.org/10.1080/01944363.2015.1126196>

- Baker, H., Moncaster, A., Remøy, H., & Wilkinson, S. (2021). Retention not demolition: How heritage thinking can inform carbon reduction. *Journal of Architectural Conservation*, 27(3), 176–194. <https://doi.org/10.1080/13556207.2021.1948239>
- Barthel-Bouchier, D. (2015). Heritage and climate change: Organizational conflicts and conundrums. In D. Harvey & J. Perry (Eds.), *The future of heritage as climates change* (pp. 151–166). Routledge.
- Berg, F., & Fuglseth, M. (2018). Life cycle assessment and historic buildings: Energy-efficiency refurbishment versus new construction in Norway. *Journal of Architectural Conservation*, 24(2), 152–167. <https://doi.org/10.1080/13556207.2018.1493664>
- Boverket. (2022). Yttrande över “Remiss av förslag till revidering av EU-direktivet om byggnaders energiprestanda.”
- Boverket. (2024). Preliminära beräkningar av gränsvärden för energiprestanda i befintliga lokalbyggnader. <https://www.boverket.se/sv/om-boverket/publicerat-av-boverket/publikationer/2024/preliminara-berakningar-av-gransvarden-for-energiprestanda-i-befintliga-lokalbyggnader>
- Boverket. (2025a). Direktiv för byggnaders energiprestanda, EPBD. <https://www.boverket.se/sv/byggande/uppdrag/direktiv-for-byggnaders-energiprestanda>
- Boverket. (2025b). Förvanskingsförbudet. <https://www.boverket.se/sv/PBL-kunskapsbanken/teman/kulturvarden/kulturvarden-i-plan---och-bygglagen/krav-pa-byggnadsverk-och-tomter/forvanskingsforbudet>
- Boverket. (2025c). Metoder, definitioner och krav inom solenergi i direktivet om byggnaders energiprestanda. <https://www.boverket.se/sv/om-boverket/publikationer/2025/solenergi-och-energiprestanda>
- Boverket. (2025d). Utsläpp av växthusgaser från bygg- och fastighetssektorn. <https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/miljoindikatorer---aktuell-status/vaxthusgaser>
- Braun, V., & Clarke, V. (2022). *Thematic analysis: A practical guide*. Sage.
- Brumann, C. (2014). Heritage agnosticism: A third path for the study of cultural heritage. *Social Anthropology*, 22(2), 173–188. <https://doi.org/10.1111/1469-8676.12068>
- Cassar, M. (2009). Sustainable heritage: Challenges and strategies for the twenty-first century. *APT Bulletin: The Journal of Preservation Technology*, 40(1), 3–11.
- Christiernsson, A., Geijer, M., & Malafry, M. (2021). Legal aspects on cultural values and energy efficiency in the built environment—A sustainable balance of public interests? *Heritage*, 4(4), 3507–3522. <https://doi.org/10.3390/heritage4040194>
- Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). (2010). *Official Journal of the European Union*, L 153/13.
- Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance). (2024). *Official Journal of the European Union*, L 2024/1275.
- Directorate-General for Education, Youth, Sport and Culture. (2022). *Strengthening cultural heritage resilience for climate change: Where the European Green Deal meets cultural heritage*. Publications Office of the European Union. <https://data.europa.eu/doi/10.2766/44688>
- Eriksson, P. (2021). *Balancing building conservation with energy conservation: Towards differentiated energy renovation strategies in historic building stocks* [Unpublished doctoral dissertation]. University of Gothenburg.
- European Commission. (2020). *A renovation wave for Europe: Greening our buildings, creating jobs, improving lives*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0662>
- Geijer, M., Christiernsson, A., & Malafry, M. (2022). Juridiken och praktiken—Energifrågor och hantering av kulturvärden i planerings- och byggprocesser. *Nordic Journal of Settlement History and Built Heritage*, 82, 33–64.

- Hagelqvist, S., Legnér, M., & Femenías, P. (2024). Energy efficiency and socio-cultural values in public policy in the city of Stockholm. *The Historic Environment: Policy & Practice*, 15(4), 540–563. <https://doi.org/10.1080/17567505.2024.2436044>
- Herrera-Avellanosa, D., Haas, F., Leijonhufvud, G., Brostrom, T., Buda, A., Pracchi, V., Webb, A. L., Hüttler, W., & Troi, A. (2019). Deep renovation of historic buildings: The IEA-SHC Task 59 path towards the lowest possible energy demand and CO₂ emissions. *International Journal of Building Pathology and Adaptation*, 38(4), 539–553. <https://doi.org/10.1108/IJBPA-12-2018-0102>
- Huuhka, S., Moisio, M., Salmio, E., Köliö, A., & Lahdensivu, J. (2023). Renovate or replace? Consequential replacement LCA framework for buildings. *Buildings and Cities*, 4(1), 212–228. <https://doi.org/10.5334/bc.309>
- Huuhka, S., & Vestergaard, I. (2020). Building conservation and the circular economy: A theoretical consideration. *Journal of Cultural Heritage Management and Sustainable Development*, 10(1), 29–40. <https://doi.org/10.1108/JCHMSD-06-2019-0081>
- ICOMOS ISCES. (2021). *Feedback from: ICOMOS ISCES*. European Commission. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Energy-efficiency-Revision-of-the-Energy-Performance-of-Buildings-Directive/F2012888_en
- Janson, U., Farsäter, K., Fransson, V., & Johansson, D. (2022). Demolish, recycle, build new or renovate—Energy use throughout the life cycle. *IOP Conference Series: Earth and Environmental Science*, 1122(1), Article 012048. <https://doi.org/10.1088/1755-1315/1122/1/012048>
- Legnér, M., & Leijonhufvud, G. (2019). A legacy of energy saving: The discussion on heritage values in the first programme on energy efficiency in buildings in Sweden, c. 1974–1984. *The Historic Environment: Policy & Practice*, 10(1), 40–57. <https://doi.org/10.1080/17567505.2018.1531646>
- Legnér, M., Leijonhufvud, G., & Tunefalk, M. (2020). Energy policy and conservation planning in Sweden: A longitudinal evaluation. *International Journal of Building Pathology and Adaptation*, 38(4), 555–572.
- Lidelöw, S., Örn, T., Luciani, A., & Rizzo, A. (2019). Energy-efficiency measures for heritage buildings: A literature review. *Sustainable Cities and Society*, 45, 231–242. <https://doi.org/10.1016/j.scs.2018.09.029>
- Martínez-Molina, A., Tort-Ausina, I., Cho, S., & Vivancos, J.-L. (2016). Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews*, 61, 70–85. <https://doi.org/10.1016/j.rser.2016.03.018>
- Myndigheten för Kulturanalys. (2022). *Kulturmiljöstatistik* (Kulturfakta No. 2022:6).
- Pendlebury, J. R. (2009). *Conservation in the age of consensus*. Routledge.
- Potts, A. (2022). *European cultural heritage green paper: Putting Europe's shared heritage at the heart of the European Green Deal*. Europa Nostra. <https://openarchive.icomos.org/id/eprint/2552>
- Regeringen. (2024). *Uppdrag att fastställa metoder och definitioner enligt direktivet om byggnaders energiprestanda*.
- Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending regulation (EU) 2019/2088 (Text with EEA Relevance). (2020). *Official Journal of the European Union*, L 198/13.
- Riksantikvarieämbetet. (2017). *Kulturvärden i planerings—och bygglovsprocesser—En utvärdering om kommuners förutsättningar att ta hänsyn till kulturvärden*.
- Riksantikvarieämbetet. (2018). *Kulturvärden förviner i byggprocessen: Intervjuer och aktgranskning av bygglovsärenden*.
- Riksantikvarieämbetet. (2025). *Bebyggelseregistret*. <https://app.raa.se/open/bebyggelse>

- Röck, M., Saade, M. R. M., Balouktsi, M., Rasmussen, F. N., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., & Passer, A. (2020). Embodied GHG emissions of buildings—The hidden challenge for effective climate change mitigation. *Applied Energy*, 258, Article 114107. <https://doi.org/10.1016/j.apenergy.2019.114107>
- Sveriges Riksdag. (1988). *Kulturmiljölag* (SFS 1988:950).
- Sveriges Riksdag. (2010). *Plan-och bygglag* (SFS 2010:900).
- Webb, A. L. (2017). Energy retrofits in historic and traditional buildings: A review of problems and methods. *Renewable and Sustainable Energy Reviews*, 77, 748–759. <https://doi.org/10.1016/j.rser.2017.01.145>
- Yarrow, T. (2019). How conservation matters: Ethnographic explorations of historic building renovation. *Journal of Material Culture*, 24(1), 3–21. <https://doi.org/10.1177/1359183518769111>

About the Author

Anna Donarelli is a PhD student in conservation at Uppsala University, and part of the cross-disciplinary research school ASSURE (Adaptation of Urban Space Through Sustainable Regeneration). She has a background in building conservation, and works on energy use, climate mitigation, climate adaptation, and sustainable renovation in existing buildings and building stocks.



URBAN PLANNING
ISSN: 2183-7635

Urban Planning is an international, peer-reviewed open access journal in the field of urban studies. With the aim of sparking discussions and providing new perspectives on the social, political, economic, and cultural dimensions of urban life, the journal welcomes multidisciplinary approaches to the study of town and city planning, design, development, and renewal.

Recognising the value of both qualitative and quantitative methods and striving to open up debates on topics as diverse as housing, transportation, technology, sustainability, citizen participation, and heritage, among others, the journal ultimately wishes to bring together urban planning and progress and quality of life.



www.cogitatiopress.com/urbanplanning