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Potential Role of Life Cycle Assessment for Cultural Heritage Conservation Practices in Türkiye

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Abstract – This study emphasizes the significance of integrating Life Cycle Assessment (LCA), a systematic method used to evaluate the environmental impacts of a process throughout its entire life cycle, as a vital tool for cultural heritage conservation in Türkiye. The research identifies gaps between current practices and the potential for sustainable development, revealing opportunities for improvement in conservation efforts. While examples from Türkiye often focus on preserving the authenticity of historical structures with visual and cultural value, energy efficiency and the environmental impacts of these buildings are frequently overlooked. An analysis of international case studies demonstrates the successful integration of LCA into restoration projects worldwide, highlighting missed opportunities for Türkiye. By applying LCA, it is possible to facilitate the selection of environmentally friendly methods and materials, promote stakeholder participation, and ensure that restoration practices prioritize sustainability. Therefore, this study aims to reveal the potential of the LCA method in cultural heritage conservation and to demonstrate how its application can contribute to the enhancement of conservation practices in Türkiye, ultimately helping to preserve its cultural heritage for future generations.

Keywords – Life Cycle Assessment (LCA), Cultural Heritage Conservation, Sustainable Conservation, Environmental Impact Assessment

I. Introduction

It recently became more apparent than ever how urgently the building industry has to adopt sustainable methods since this sector accounts for up to 50% of all greenhouse gas emissions and makes a substantial contribution to the world's energy consumption [1]. As our planet faces challenges with the exploitation of resources and climate change, the implementation of Life Cycle Assessment (LCA) has emerged as a crucial tool for evaluating the environmental impacts of buildings throughout their life cycles, from raw material extraction to construction, operation, and inevitable demolition [2], [3].

Advancements in LCA methodology have strengthened its reliability and broadened its applicability, allowing for more comprehensive assessments. This helps prevent the transfer of environmental burdens from one impact category to another [4]. Additionally, LCA provides a methodical framework for guiding sustainable design practices and decision-making, supporting the larger objective of sustainable development as the construction industry comes under increasing pressure for its ecological footprint [1], [3]. This synthesis emphasizes how important it is to incorporate LCA into building processes to successfully reduce the negative environmental effects.

Recent studies highlight the growing importance of Life Cycle Assessment (LCA) in evaluating the environmental impacts of building refurbishments, with a focus on energy efficiency [5]. LCA has evolved into Life Cycle Sustainability Analysis (LCSA), addressing environmental, social, and economic factors [6]. Integrating social and economic dimensions through LCSA is crucial for thorough sustainability evaluations, especially in the building industry [7]. However, the existence of various methodologies and functional units complicates its use as a decision-making tool and emphasizes the need for standardized approaches [8]. Although LCA offers insightful information, constraints such as subjectivity and data quality still exist [9]. Improved assessments of sustainability and well-informed decision-making depend on methodological developments, such as dynamic and interdisciplinary approaches [10].

Despite the growth in LCA applications, there is a notable gap in the assessment of traditional buildings, which are frequently disregarded in favor of low-energy designs [11]. The main goal of the conservation projects is to preserve, rehabilitate, or adapt existing structures of cultural or historical significance. These projects improve both the aesthetic and functional qualities of the built environment and are expected to support sustainability by limiting the need for new construction and decreasing material waste. Therefore, LCA has emerged as a key instrument in the conservation and restoration of cultural heritage while offering a framework for analyzing the environmental, economic, and social effects of these processes [12].

Although widely used in various industries, the application of LCA in cultural heritage conservation is still in its early stages, with the potential to improve decision-making [13]. Because of their historical and cultural significance, heritage buildings need sustainable strategies that take into account both their distinctive qualities and the socioeconomic conditions in which they are situated [14]. To conserve cultural heritage for future generations, LCA implementation may

provide helpful details regarding the long-term viability of restoration projects.

Another point that stands out from studies is the importance of evaluating the environmental consequences of selecting suitable materials and preservation techniques, as this shows the critical gap in the awareness of their ecological footprint [15]. Cultural heritage professionals can also systematically assess the implications of their choice of materials and methods in conservation by adopting LCA. This strategy is further strengthened by the adoption of circular economy techniques, which promote the adaptive reuse of historic structures in order to reduce waste production and resource extraction [16]. LCA's capacity to offer a thorough evaluation of the environmental, economic, and social effects will help drive the shift to more environmentally friendly methods of managing cultural heritage as it gains recognition as a decision-support tool [17]. This holistic perspective supports the conservation of cultural assets while contributing to broader sustainability goals in the built environment.

Building on these insights, the research seeks to explore the potential role of Life Cycle Assessment (LCA) in advancing cultural heritage conservation practices in Türkiye. The topic remains underexplored in the country, largely due to limited awareness, insufficient legislative frameworks, and the complexities posed by insufficient expertise. By addressing these barriers, the study aims to highlight how LCA can provide valuable insights for making heritage conservation more sustainable while balancing environmental, economic, and social considerations in the Turkish context.

II. Research Methodology

This study aims to explore the transformative potential of Life Cycle Assessment (LCA) in cultural heritage conservation and uses a conceptual framework that is built around five key steps (Fig. 1). It begins with a comprehensive introduction that points out the significance of *"LCA as a Tool for Environmental Impact Assessment"* for restoration practices as various materials and methods are systematically assessed by stakeholders to minimize the negative environmental impacts during conservation processes. This initial analysis of the *"Application of LCA in Cultural Heritage Conservation"* demonstrates the applicability of LCA within the specific context of cultural heritage. Several case studies around the world, where LCA tools are employed, demonstrate how LCA leads decision-making and improves sustainability outcomes such as reduced waste and lower carbon footprints. By connecting these findings to the Turkish context, the aim is to illustrate the importance of a holistic approach that respects both ecological and cultural values.

As the study progresses, *"Gaps in Turkish Restoration Projects"* are identified as the third step. In the literature review, LCA examples from Türkiye and the methodologies used in these studies have been examined. Even though the value of LCA is becoming more widely acknowledged, this tool is not consistently used in many restoration projects in Türkiye. By identifying these gaps, the study reveals the obstacles preventing local practices from implementing LCA. To enrich the discussion, the study conducts a *"Comparison with International Best Practices."* By presenting efficient LCA implementations and diverse methodologies from the world, this comparative analysis offers insights that could potentially be applied to the Turkish context. This cross-comparative perspective broadens the understanding and aims to offer practical insights for practitioners.

Ultimately, the research establishes *"LCA as a Critical Tool for Sustainable Conservation."* It promotes the incorporation of LCA into conventional conservation efforts in Türkiye by drawing on the knowledge gathered from past evaluations. By combining results, the study aims to show how the methodical use of LCA is significant in more sustainable conservation initiatives, guaranteeing that places of cultural heritage are conserved for their historical value while honoring and safeguarding the environment.

Fig. 1 Conceptual Framework of the study

III. Literature Review

Since historical buildings have cultural and visual relevance, restoration works are generally carried out to conserve the buildings' original appearance without considering their energy consumption [18]. For this reason, studies on integrating the LCA method in restoration are very limited in the literature. Although studies have recently increased in the literature due to growing concerns about sustainability and climate change, the use of LCA in historical contexts has generally remained theoretical. In this study, sources from different case studies were examined, and the literature review was divided into two parts: global sources and Turkish sources, which were evaluated for comparison.

A. Global Perspective on LCA in Restoration

The LCA method in cultural heritage restoration has been impeded due to social and technical complexities until the appearance of new understandings that take a phased approach to restoration and consider material reuse or recycling [12]. With the changing approaches and emergence of sustainability concerns, LCA has been applied in various cases globally by integrating environmental sustainability into heritage conservation.

Table 1. Global Examples of using the LCA method for cultural heritage restoration

Title	Author-Year	Keyword	Method	Location
Improving sustainable cultural heritage restoration work through life cycle assessment based model	Settembre Blundo et al. 2018	Sustainability Cultural heritage Life cycle assessment (LCA) Life cycle costing (LCC) Social life cycle assessment (S-LCA)	Integrated LCA by introducing CH-LCM Model	Spain
Green Maintenance for Heritage Buildings: an Appraisal Approach for St Paul's Church in Melaka, Malaysia	Kayan et al. 2018	Environmental Maintenance Impact (EMI) Green maintenance Heritage building Laterite stones Life Cycle Assessment (LCA)	cradle-to-site LCA with embodied carbon	Malaysia
Environmental and social impact assessment of cultural heritage restoration and its application to the Uncastillo Fortress	Khorassani et al. 2019	Cultural Heritage Enhancement Environmental impact Life Cycle Assessment Life Cycle Sustainability Assessment Social Impact Social Life Cycle Assessment	Ecological and Social assessment	Spain
Life cycle assessment as a decision-making tool for selecting building systems in heritage intervention: Case study of Roman Theatre in Italica, Spain	Gómez de Cózar et al. 2019	Life cycle assessment Architecture Environmental impact Heritage	LCA as a decision making tool	Spain
Planning a Life Cycle Analysis Library and Beta Tool for Sustainable Cultural Heritage Preservation and Exhibition Practices	Nunberg et al. 2019		cradle-to-gate LCA	US
Environmental impacts assessment for conversion of an old mill building into a modern apartment building through reconstruction	Sedlakova et al. 2020	Residential buildings Reconstruction Life cycle assessment (LCA) Environmental impacts Sustainability Greenhouse gases	Environmental Impact Assessment through cradle-to-gate LCA	Slovakia
Urban Heritage Life Monitoring: as a Proactive Tool for Sustainable Heritage Areas	Bashandy and Abd Elaziz 2020	Life Cycle Assessment Urban Life Cycle Heritage Areas Urban Resilience	Urban Heritage Life Monitoring Tool and semi-structured interviews by combining LCA and resilience cycle theory	Egypt
Evaluation of Life-Cycle Assessment Analysis: Application to Restoration Projects and New Construction in Alpine Climate, Japan	Endo and Takamura 2021	Restoration Heritage Architecture Life cycle assessment (LCA) Timber-frame Structure Residential Building	LCA with greenhouse gas emissions and operational energy use calculations	Japan
Life cycle GHG assessment of a building restoration: Case study of a heritage industrial building in Toronto, Canada	Opher et al. 2021	LCA Net zero carbon Refurbishment Sensitivity analysis Data collection Embodied carbon	cradle-to-grave LCA with assessment of embodied greenhouse gas emissions	Canada
Comparative Life-Cycle Assessment of restoration and renovation of a traditional Danish farmer house	Serrano et al. 2022	LCA Sustainability Climate impact Building transformation Energy efficiency Architecture	cradle-to-grave LCA	Denmark
Assessing the environmental benefits of adaptive reuse in historical buildings. A case study of a life cycle assessment approach	Hu and Świerzawski 2024	Adaptive reuse life cycle assessment historical building environmental impact	Environmental Impact Assessment through LCA	Poland

One of the countries that stands out with its different approaches to the use of LCA for cultural heritage restoration is Spain. In the Uncastillo Fortress restoration projects, the LCA was applied as a part of a holistic and integrated method that consists of environmental, social, and economic impact assessments to ensure sustainable heritage management by considering all the branches of sustainability [13], [19]. Apart from these holistic approaches, in another restoration project in Spain, which is the case of the Roman Theatre in Italica, LCA was used as a tool to decide on the most appropriate construction system and materials for intervention in the heritage site by comparing the environmental impact of the proposed aluminium, wood, and steel materials [20]. Using LCA as a selection tool in cultural heritage restoration is not limited to the example in Spain. In Malaysia, the cradle-to-site LCA method enabled the assessment and comparison of the environmental impacts of repair methods for laterite stone in terms of carbon emissions in the restoration project of St. Paul's church. Comparing the repair methods with LCA in this study sheds light on selecting more sustainable repair methods without damaging the authenticity [21]. In addition to applying LCA as a decision-making tool in selecting sustainable methods and materials for the repair or intervention of historical buildings, there are also frequent examples of its use in comparing the sustainability of traditional and new buildings. In Slovakia, the LCA method with the cradle-to-gate approach was used to determine the environmental effects of converting an old mill building into a residential building, and it was understood that the conversion of the building was more sustainable than demolishing and constructing a new building [22]. Similarly, in a study in Japan, the environmental effects of the restoration of historic buildings and the construction of new buildings in terms of greenhouse gas emissions and operational energy use were compared by LCA [23]. Since the historical buildings in the region are located in the cold alpine climate, energy use is an essential focus of the study. Moreover, in Denmark, a similar study was made to examine whether restoration carried out using traditional materials while preserving the original appearance of historical buildings can have similar environmental performance compared to renovation carried out using modern materials focused on energy efficiency in a Danish farmer house by applying LCA [18]. Therefore, there is an effort to balance environmental sustainability with heritage conservation. Similarly, in a study in Poland, LCA played a vital role in understanding that adaptive reuse is a better method than demolition and rebuilding in terms of sustainability by comparing environmental impacts [24]. Apart from these cases that compare the sustainability of traditional and new buildings, in Canada, LCA was used for carbon neutrality in historic production buildings [25].

Besides building scale approaches, there is an innovative project about using LCA in artifact restoration in the US. In this project, an online library that shows the environmental impacts of cultural heritage artifacts in terms of materials and methods for LCA was established to inform people about the sustainable conservation of artifacts [26]. In addition to the artifact and building scale applications, in Egypt, an urban scale approach was applied through the Urban Heritage Life Monitoring Tool (UHLMT) incorporated LCA to provide sustainability for both physical characteristics and identity [27]. Therefore, LCA is a method used in different contexts and scales. It has the potential to enhance the sustainability of heritage sites while conserving authenticity, and these cases show how LCA can support sustainable decision-making in diverse contexts.

In the cases of using LCA in cultural heritage restoration, methodologies vary from case to case. While the LCA for restoration studies in Spain focuses on sustainability holistically, including economic, social, and environmental aspects [13], [19], studies have generally focused on environmental impacts worldwide. The assessment of environmental impacts is also carried out by focusing on different criteria according to the cases. In the Slovakia example, environmental impacts, including energy consumption, global warming potential, and greenhouse gas emission, were evaluated with the cradle-to-gate approach [22]. Similarly, in Poland's case, environmental impacts were determined comprehensively by considering global warming, smog formation, and acidification [24]. In Malaysia and Canada, studies focusing more on carbon emissions were followed [21], [25]. In the case of Japan, energy consumption was the focus of the study because of the colder climate [23]. In the Denmark case, a cradle-to-grave approach was followed by focusing on materials and measuring energy efficiency [18]. Additionally, an approach towards digitalization was determined in the US example [26], while methods such as semi-structured interviews were included in LCA analyses in the Egypt case [27].

In conservation projects where the LCA method is applied, various outcomes have emerged in terms of sustainability around different themes such as material use, social impacts, and comparison of the traditional and the new. In terms of material use, outcomes have shown that using local materials, reuse of materials, selection of lightweight materials, and use of low-carbon materials provide sustainability by reducing carbon emissions. For example, in the Uncastillo Fortress projects in Spain, local materials reduced energy consumption and improved sustainability [13], [19]. Moreover, in St. Paul's Church case in Malaysia, the reuse of materials reduced carbon emissions and supported long-term sustainability [21]. Furthermore, in the Roman Theatre in Spain, selecting lightweight materials reduced environmental impact [20]. In Canada's case, choosing low-carbon and eco-friendly materials contributed to carbon neutrality [25]. Apart from the use of materials, the LCA method in restoration has also had social outcomes. For example, community engagement leads to improved sustainability and new employment opportunities in the Uncastillo Fortress projects in Spain [13], [19]. Additionally, in the case of Egypt, the sustainability of cultural identity in urban heritage areas was ensured with community participation [27]. Apart from these, outcomes have emerged regarding the comparison of the traditional with the new. In the Slovakian and Polish examples, it has been shown that the adaptive reuse of old buildings produces less waste than new construction, thus reducing environmental impacts [22], [24]. Moreover, in the example in Japan, restoration is a more sustainable method, as it uses less material and produces less waste than new construction, despite the cold climate [23]. Furthermore, in the Denmark case, it has been found that repair with traditional materials is more energy efficient than renovation with new materials [18]. Thus, integrating the LCA method in cultural heritage projects has various outcomes, and with this method, cultural heritage conservation can be achieved by taking into account sustainability requirements.

B. LCA in the Turkish Context

One of the major challenges decision-makers face in the field of cultural heritage is achieving sustainable restoration since the LCA application in restoration remains in the early stages despite being extensively utilized across numerous industries and service sectors [13]. This gap can be further observed when it comes to widening countries like Türkiye since the literature shows a limited number of cases.

Table 2. Examples from Türkiye that use the LCA method for cultural heritage restoration

Title	Author-Year	Keyword	Method	Location
Life Cycle Assessment of Traditional Buildings: Evaluation of Old Diyarbakır Houses by LEED	Taygun et al. 2016	Traditional Buildings, Diyarbakır Houses, Eco-Friendly Buildings, Life Cycle Assessment, LEED	LEED Certification, eco-friendly properties	Diyarbakır
Methodological approach for performance assessment of historical buildings based on seismic, energy and cost performance: A Mediterranean case	Güleroğlu et al. 2020	Historical building Performance-based design Seismic retrofit Energy retrofit The net present value	Life-cycle cost analysis and energy simulations	İzmir
The impacts of restoration and reconstruction of a heritage building on life cycle energy consumption and related carbon dioxide emissions	Atmaca et al. 2021	Energy consumption Embodied energy Carbon dioxide emissions Heritage buildings Restoration Life cycle assessment	Embodied energy and carbon	Gaziantep
Contribution of Cultural Heritage and Architectural Conservation to the Circular Economy and Sustainability: An Evaluation in The Case of Turkey	Dişli 2022	Cultural heritage, Architectural conservation, Circular economy, Sustainability, Turkey	Review, circular economy	Türkiye
Life Cycle Assessment of Internal Wall Panels: A Case Study of Sumerbank Kayseri Textile Factory Restoration Process	Kırılmaz and Metin 2023	Ecosystem Quality Human Health Internal Wall Panels Life cycle Assessment Resource Use	LCA for comparisons	Kayseri

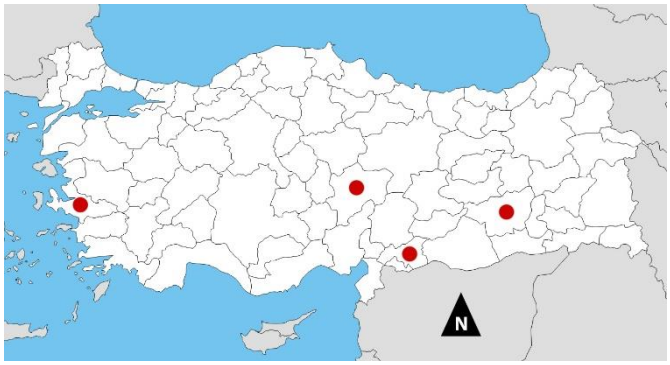

Fig. 2 The location of Turkish examples

The current restoration practices in Türkiye demonstrate certain gaps and indicate an opportunity for growth. The review of the existing literature reveals that the use of LCA and similar methods in conservation is limited in Türkiye when it comes to the consideration of energy efficiency. The number of examples highlights the importance of these practices along with the current challenges. One crucial finding is the historical buildings show low scores in terms of performance. In an example from Diyarbakır [28], the study shows that the 3 selected traditional buildings were failing scores in LEED (Leadership in Energy and Environmental Design) Certification despite their environmental usage of materials and expectations that they would receive high marks for being environmentally friendly. The findings showed that the homes do not receive enough points to be certified, and the primary causes of this result are the inapplicability of current evaluation systems to traditional buildings, regionally-focused architectural solutions, and the requirement that specific building products be included in the systems. Therefore, the researchers offer new scoring systems for the evaluation of historical structures. Similarly, one study [29] compares the life cycle energy consumption (LCEC) and carbon dioxide emissions (LCCE) of a heritage building from 1875, a modern building with a similar plan, and the same heritage building after restoration, using real data from a project in Gaziantep. Results show that the heritage building has the highest operational energy consumption, the modern building is the most energy-efficient overall, while the restored heritage building reduces energy consumption and emissions but still remains less efficient.

Another finding from the literature is the importance of raising awareness as one of the researchers [30] states that historical buildings inherently demonstrate sustainability through the use of local materials, construction techniques, and their adaptation to the local environment, climate, and topography. It emphasizes how the reuse of historic buildings contributes to the circular economy by further encouraging widespread awareness on the topic. On the other hand, the need for the reuse of traditional buildings for environmental, economic, and social benefits is encouraged, but it is seen that the potential for energy saving is undermined by many other qualities, such as seismic performance. A study [31] shows

how to evaluate seismic and energy performance in a historic building in İzmir using a multidisciplinary approach that involves four phases: assessing the energy performance at the moment, choosing retrofit packages, analysing the results in terms of cost and energy, and determining how effective the measures are. Based on the results, the best measures to improve energy, seismic, and cost performance were replacing the HVAC system and upgrading the external walls. Moreover, LCA was also used for the determination of ideal internal wall panels in another study [32]. The case study compares three commonly used wall panels in Türkiye, which are gypsum, reinforced gypsum, and cement-based panels, using Life Cycle Assessment (LCA) with *SimaPro* software and data from the *EcoInvent* database. Results show that reinforced gypsum has the highest environmental impact, followed by cement, with gypsum panels having the least impact.

It is important to note that the current examples have come from the generally warmer climates of Türkiye, and the possible new challenges from other regions are unexplored to begin with (Fig. 2). However, based on the examples, the limited use of LCA in Türkiye can be attributed to several factors, including inefficient frameworks for traditional building materials and construction techniques in terms of energy performance and sustainability, lack of awareness and expertise in the field, insufficient policy support, and limited dissemination on long-term sustainability outcomes. This gap suggests a significant opportunity for integrating LCA into restoration practices, which could enhance the sustainability of projects while preserving architectural heritage in an environmentally responsible manner.

IV. Results and Discussion

The literature review of global and Turkish case studies highlights the role of LCA, showcasing the similarities and differences between conservation practices.

A. Comparison of Turkish Case Studies with International Examples

In Türkiye, the integration of Life Cycle Assessment (LCA) in restoration projects remains scarce despite the country's abundant cultural heritage and numerous restoration activities. This limited implementation reflects a gap between the goals of conservation and the broader global shift toward sustainable building practices. As a result, Turkish restoration projects often overlook opportunities to reduce their carbon footprint, optimize resource use, and minimize environmental degradation. The lack of LCA in Turkish restoration projects has several consequences, including the continued use of traditional materials and methods that may not align with modern sustainability goals. Without LCA, there is no comprehensive evaluation of the environmental trade-offs involved in material selection or construction processes. This oversight leads to missed opportunities for integrating recycled or locally sourced low-impact materials, which could significantly reduce waste and energy consumption. Moreover, the absence of LCA restricts the potential for Türkiye's restoration projects to align with international sustainability standards, limiting the country's progress in green building practices.

In contrast to Türkiye, several countries have successfully integrated LCA into their restoration practices, offering valuable lessons. For instance, Germany has implemented LCA in multiple heritage conservation projects, particularly in assessing the sustainability of retrofitting traditional buildings with modern energy-efficient systems. This approach has led to significant reductions in energy consumption and carbon emissions while preserving the buildings' historical integrity. Similarly, in the United Kingdom, LCA is regularly used in restoration projects to compare the environmental impacts of different materials, helping decision-makers choose options that are both sustainable and culturally appropriate.

Therefore, it is crucial that the frameworks on energy efficiency expend their data on traditional building materials and construction techniques from Türkiye to assess the conditions as precisely as possible to lead to proper precautionary measures. Their adaptation to the local environment, climate, and topography are also must-have indicators since these attributes should not be treated as independent indicators. Moreover, the lack of awareness about LCA, concerns regarding energy efficiency, and limited expertise in the field are closely tied to existing policies and practices that neither prioritize nor promote these issues. This contrasts with global examples where sustainability is given greater importance. It is unsurprising that sustainability may not be prioritized when it is not explicitly required, especially given the high costs associated with planning and construction. This is closely linked to the limited focus on the social and economic dimensions of the issue as well.

B. Potential of LCA in Turkish Restoration Projects

Since cultural heritage sites constitute a significant part of the built environment, it is vital to evaluate these areas in terms of energy efficiency and sustainability. In this direction, as can be understood from the sources analysed in the literature review, implementing the LCA method in cultural heritage conservation studies has various benefits.

The first benefit of applying the LCA method in cultural heritage conservation is effective resource management. During the assessment process, LCA identifies opportunities for more efficient use of resources, such as optimizing water, energy, and material use. In addition, these assessments allow the selection of the most efficient materials and construction techniques that can be used for conservation works. For example, in the case of St. Paul's Church in Malaysia, reusing old materials by repairing them rather than using new materials was a more effective method for long-term sustainability [21]. Additionally, in the case of the Roman Theatre in Spain, selecting lightweight materials had less harmful environmental impacts [20]. Therefore, in restoration projects in Türkiye, the LCA method has the potential to be a decision-making tool for ensuring long-term sustainability and reducing harmful environmental impacts by playing a role in the selection of restoration techniques and materials in relation to the local context. With LCA, waste production is reduced, carbon emissions are diminished, and a sustainable built environment can be provided while the authenticity of the heritage buildings is conserved through a systematic dedication-making tool.

Another benefit of applying LCA to conservation work is social development. Studies conducted by evaluating social values together with LCA can increase participation in cultural heritage conservation work, leading to the emergence of more accurate conservation approaches and supporting the social pillar of sustainability. There are various successful studies in the literature on this subject globally [13], [19], [27]. In Türkiye, the implementation of LCA with social sustainability

can positively affect the success of the restorations by engaging different stakeholders in the process in all stages of the buildings. This would not only raise awareness and promote the dissemination of best practices but also foster a holistic approach to policy development through participatory decision-making processes that empower environmentally conscious individuals and stakeholders to influence the outcomes.

The last benefit of the integration of LCA into conservation works is sustainability improvement. In decisions taken for historical buildings that have lost their functions, the LCA method has shown that conserving these buildings with minimal intervention is a more environmentally friendly and sustainable approach than demolishing them and constructing a new building in their place. Thus, LCA has become a method that emphasizes the importance of cultural heritage conservation efforts. In interventions against historical buildings, instead of demolishing them, restoration methods that produce less waste, consume less energy, reduce carbon emissions, and use more environmentally friendly methods have been selected, and thanks to the LCA method, the sustainability of the built environment has been improved [22], [24]. Therefore, while determining methods for how to intervene against historical buildings in Türkiye, conserving them with LCA can prevent the destruction of structures by demolishing them and lead to more sustainable results.

C. Limitations and Suggestions for Improvement

After analysing many case studies and comparing global examples with the examples in Türkiye, there are some aspects that are noticed. Firstly, one of the main reasons for the limited use of LCA methods in projects is the lack of sufficient awareness among managers and project implementers regarding the integration of these practices. When working on restoration projects, many architects, engineers, and project managers can put project schedules and historical authenticity ahead of environmental considerations. Decision-makers could not perceive the benefit of devoting time and money to carrying out such evaluations if they lack adequate understanding of how LCA contributes to sustainable results. On the other hand, if LCA methods are integrated into the planning and design phases, environmental sustainability would be prioritized from the outset, enabling more informed decision-making and better alignment with long-term conservation goals. This disparity may be closed, and the application of LCA in conservation projects might be encouraged by increasing awareness via educational and training initiatives.

The lack of LCA-related experience and technical know-how in Türkiye's building and repair industries is another significant obstacle. Specialized abilities are needed to implement LCA, such as the capacity to evaluate material impacts during a building's life cycle and analyse intricate environmental data. Professionals with the skills required to carry out these evaluations correctly are now in limited supply. Therefore, even if there is a desire to use LCA, its successful application is hampered by a shortage of qualified staff. This problem may be solved by increasing capability through professional growth and cooperation with global specialists. Working with international institutions and experts can significantly improve professionals' technical expertise, ensuring they stay updated with the latest methodologies and tools.

The final observed limitation of LCA practices is the lack of regulations and guidelines. Current regulations prioritize cultural preservation over environmental sustainability, missing emphasis on LCA. Without supportive policies or incentives, professionals have little motivation to adopt LCA, and the absence of a standardized framework further complicates its implementation. Clear policies and incentives could promote its integration and encourage wider adoption of LCA in restoration projects, making sustainability a core consideration alongside cultural preservation.

V. CONCLUSION

This study underscores the importance of establishing Life Cycle Assessment (LCA) as a vital tool for conservation in Türkiye, addressing challenges such as inefficient frameworks for traditional building materials and construction techniques, a lack of awareness and expertise in the field, insufficient policy support, and limited dissemination of long-term sustainability outcomes. By identifying the gap between current practices and the potential for sustainable development, the study highlights opportunities for improvement. While restoration efforts in Türkiye primarily focus on preserving historical authenticity, environmental sustainability remains underexplored. The analysis of international examples demonstrates how effectively LCA has been integrated into restoration projects worldwide, emphasizing the missed opportunities for Türkiye to utilize LCA to achieve both conservation and sustainability goals.

The application of LCA into restoration in Türkiye is very important for the integration of sustainability standards and conservation. With the LCA, methods and materials with less environmental impact can be selected for conservation. In addition, a more holistic conservation approach can be followed by increasing the participation of more stakeholders and the public in using LCA methods in conservation. In addition, with the LCA method, more accurate conservation approaches can be followed by emphasizing that the restoration is more environmentally friendly rather than destruction. Therefore, the use of LCA can help to make conservation work more environmentally sensitive by paving the way for longer-term and holistic sustainability.

Future research should focus on developing specific methodologies and guidelines for the implementation of LCA in Turkish restoration projects tailored to the country’s unique cultural and environmental context. Additionally, efforts should be made to build capacity and increase expertise through training programs and international collaborations. Policymakers are encouraged to establish supportive regulations and incentives that promote the integration of LCA, ensuring that it becomes a standard practice in restoration projects. By addressing these areas, Türkiye can advance its restoration practices toward a more sustainable and responsible approach, preserving its cultural heritage for future generations.

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