INTERGENERATIONAL ARCHITECTURE FOR SUSTAINABILITY PREDICTION AND RESTORATION WITH AI

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Abstract. *This study explores how artificial intelligence (AI) can support inter-generational sustainability in architecture by transforming the way we design, evaluate, and preserve the built environment. It focuses on three main roles of AI: generating low-impact architectural solutions, predicting long-term performance of buildings and cities, and restoring cultural heritage as a resource for future generations. AI-driven tools can rapidly propose and optimize design options for facades, layouts, and structures, reducing material use, energy demand, and operational emissions across a building's life cycle. Predictive models enable architects and planners to anticipate energy consumption, climate risks, and patterns of human movement, helping shape resilient spaces that remain functional and inclusive over time. In heritage contexts, AI can reconstruct "digital twins" of damaged sites from scans and historical records, informing careful restoration and extending access to cultural memory. The paper also discusses how meaning, ethics, and responsibility evolve when AI becomes a co-designer. It argues that while AI can improve efficiency and expand creative possibilities, inter-generational sustainability still depends on human judgement, cultural understanding, and ethical oversight. Rather than replacing architects, AI should act as a partner that strengthens long-term environmental and cultural stewardship in architectural practice.*

Keywords: *Inter-Generational Architecture; Artificial Intelligence; Sustainability; Performance Prediction; Heritage Restoration.*

1. Introduction

The growing integration of artificial intelligence into architecture coincides with an urgent need to rethink sustainability across the full life cycle of the built environment. The buildings and construction sector remains one of the largest contributors to global energy demand and carbon emissions, accounting for 32% of global energy consumption and 34% of global CO_2 emissions according to the latest UNEP Global Status Report [1]. At the same time, architecture is increasingly expected to address not only environmental performance in the present, but also resilience, adaptability, and cultural continuity for future generations. In this context, sustainability can no longer be understood only as technical efficiency; it must also include long-term stewardship of spatial quality, social usefulness, and heritage value.

Artificial intelligence has emerged as a significant force in this transformation. Recent review studies show that AI is now applied across architectural design, urban planning, construction management, building performance modelling, and conservation practice. It supports generative design, optimization, simulation, decision-making, predictive analytics, and digital representation. However, these developments also raise concerns about authorship, bias, loss of architectural identity, and the tendency to prioritize measurable efficiency over human experience and cultural meaning. For that reason, AI in architecture should be examined not only as a technical innovation, but also as a shift in professional responsibility [2].

This paper approaches the subject through the concept of **intergenerational architecture**, understood here as an architectural approach that seeks to reduce environmental burden, maintain functional relevance over time, and preserve cultural memory for future users. Within this framework, AI becomes relevant in three interconnected ways: first, by generating low-impact design alternatives; second, by predicting long-term building and urban performance; and third, by assisting the restoration and digital preservation of heritage environments. The central argument of the paper is that AI can strengthen intergenerational sustainability, but only when it remains guided by human judgment, ethical control, and cultural interpretation.[3]

2. Methodology

This study is designed as an **analytical review paper** supported by a PRISMA-informed approach to literature selection and synthesis. PRISMA 2020 provides a structured framework for reporting why a review was conducted, how sources were identified, how they were screened, and how the final body of literature was selected. Although the present paper does not aim to produce a statistical meta-analysis, the PRISMA logic is useful for maintaining methodological transparency and avoiding a purely narrative or impressionistic overview.

The review focuses on recent peer-reviewed studies dealing with AI in architecture, sustainability-oriented design, performance prediction, digital twins, and heritage restoration. Priority was given to publications from 2021–2026 in order to reflect the rapid development of AI methodologies and the changing scope of their application in the built environment. The literature was examined through four stages: identification of relevant publications, screening of titles and abstracts, full-text eligibility assessment, and thematic synthesis. Rather than summarizing each source separately, the material was organized into three analytical domains aligned with the title and abstract of the paper: **AI-driven generation**, **AI-based prediction**, and **AI-assisted restoration**.

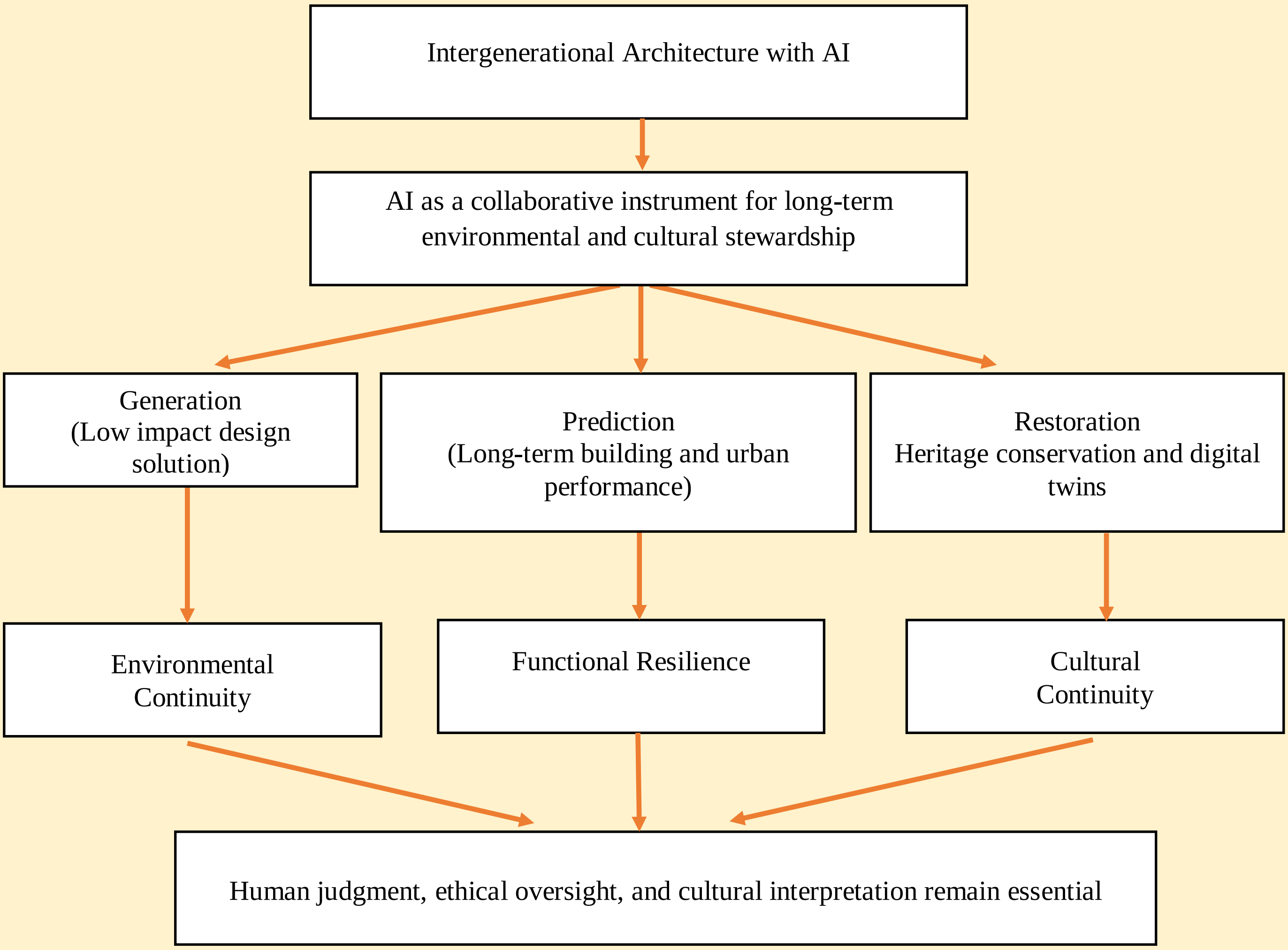
3. Intergenerational Sustainability as an Architectural Framework

Intergenerational sustainability in architecture extends the conventional environmental understanding of sustainability. It refers not only to lowering emissions or improving energy efficiency, but also to designing and preserving built environments in ways that remain beneficial across time. This involves three dimensions. The first is environmental continuity, which includes reduced material consumption, lower operational energy demand, and better climatic performance. The second is functional resilience, meaning that buildings and urban spaces should remain adaptable, safe, and usable under changing social and climatic conditions. The third is cultural continuity, which concerns the preservation of memory, identity, and heritage as part of the long-term value of the built environment. Sustainable architectural conservation literature increasingly frames heritage as an intergenerational responsibility rather than a purely aesthetic or historical issue [1].

Within this framework, AI is valuable not because it automates design for its own sake, but because it expands architecture's ability to think across time. It can help designers test the long-term consequences of present decisions, simulate future performance, and preserve the informational basis needed to restore damaged or threatened heritage. At the same time, intergenerational sustainability requires judgment about what should be optimized, what should be preserved, and whose future is being prioritized. These are questions that remain fundamentally human.

These interconnections are summarized in Figure 1. The figure illustrates the three analytical domains of the study: AI-driven generation, long-term performance prediction, and heritage restoration, and links them to the three dimensions of intergenerational sustainability: environmental continuity, functional resilience, and cultural continuity.

Figure 1. Conceptual framework of intergenerational architecture with AI.



Source: Author, 2026.

4. AI-Driven Generation for Low-Impact Architectural Design

One of the most visible applications of AI in architecture is generative design. AI-supported generative workflows can rapidly produce and compare multiple design alternatives based on parameters such as site conditions, climate, orientation, program, and performance targets. Recent reviews show that these methods are increasingly integrated into early-stage design, where they allow architects to explore more options than would be feasible through manual iteration alone. In sustainable design, this capacity matters because the earliest design decisions often determine building form, daylight access, ventilation potential, shading performance, and material intensity across the whole life cycle.

The strongest contribution of AI-driven generation lies in linking form generation with performance evaluation. Research on automated floorplan generation with energy efficiency optimization shows that AI can combine spatial planning, energy simulation, and iterative optimization in one workflow. Such systems can improve heating, cooling, daylight, and comfort metrics while reducing the time required for exploration. Studies reviewed in recent literature report measurable improvements in building energy performance when generative and evaluative processes are integrated rather than kept separate. This makes AI particularly relevant to intergenerational sustainability, since low-impact design is not only about formal novelty but about reducing long-term environmental costs from the start. [3]

At the same time, generative AI has clear limitations. Optimization tends to privilege quantifiable variables, while many architectural values remain difficult to formalize, including atmosphere, social meaning, and embodied experience. Recent scholarship therefore warns that high-performance generation can become reductive if it treats users only as datasets or replaces design judgement with automated selection. For this reason, AI should support early sustainable decision-making without narrowing architecture to what is easiest to measure. Intergenerational architecture requires solutions that are not only efficient, but also livable, legible, and culturally situated. [2]

5. Predictive AI and Long-Term Building Performance

If generation concerns the creation of options, prediction concerns architecture's ability to think ahead. AI-based predictive models are increasingly used to estimate building energy use, thermal comfort, occupancy behaviour, maintenance needs, and climate-related risks. Review studies show that predictive AI is becoming central not only to smart building operation but also to design-stage decision-making, where it can provide faster feedback than repeated full simulation. In bioclimatic and sustainable design research, AI and digital twins are being used together to support more adaptive and data-informed performance strategies. [4]

This predictive capacity is crucial to intergenerational sustainability because a building's value cannot be assessed only at the moment of completion. A design that appears efficient on paper may underperform over time, become maladapted to climate change, or fail to support changing patterns of use. Predictive models help bridge this temporal gap by forecasting probable future behaviour. They can assist with estimating energy demand under different climatic scenarios, identifying performance vulnerabilities, and informing resilient design choices before construction begins. In this sense, AI enables architecture to move from static object production toward more anticipatory and lifecycle-oriented practice.[1]

However, predictive intelligence is only as reliable as the assumptions and datasets behind it. The literature repeatedly notes the risks of biased training data, oversimplified user models, and the persistent performance gap between simulated and actual building behaviour. Prediction can strengthen sustainable design, but it does not remove uncertainty. Instead, it should be understood as a decision-support mechanism that improves foresight while still requiring professional interpretation. Within an intergenerational framework, this means AI can inform future-oriented design, but architects remain responsible for balancing efficiency, inclusiveness, risk, and long-term public value.[2]

6. AI in Restoration, Digital Twins, and Cultural Continuity

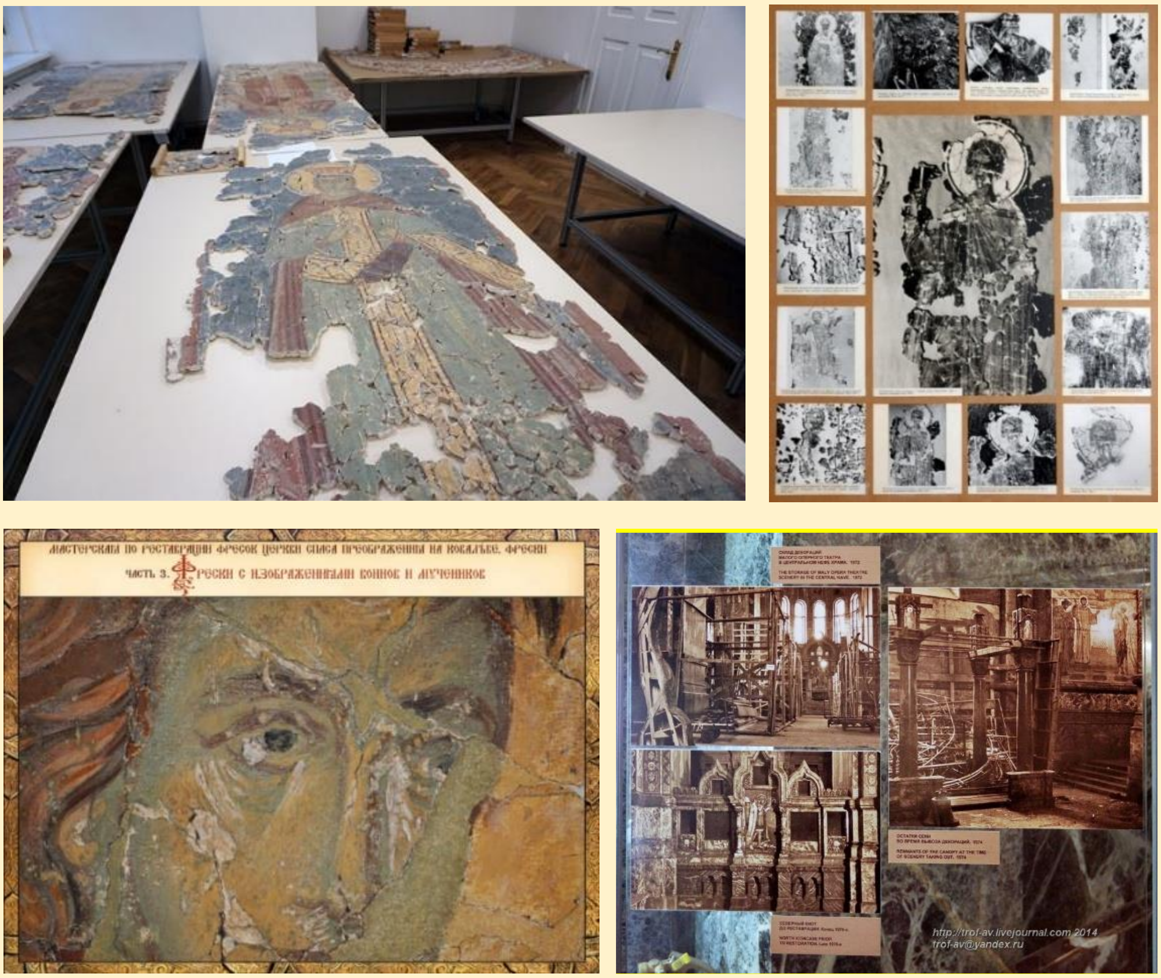
The intergenerational role of architecture is not limited to new construction. It also includes the preservation and transmission of heritage. In this domain, AI contributes through monitoring, damage detection, deterioration risk assessment, digital reconstruction, and the creation of digital twins. A recent systematic review of AI in architectural heritage conservation identifies five key phases in which AI is increasingly applied: monitoring, damage identification, environmental prediction, deterioration risk assessment, and environmental control. This demonstrates that AI in heritage is no longer restricted to visualization; it is becoming part of evidence-based conservation management [5].

Digital twins are especially important because they allow heritage sites to be represented as dynamic, data-rich environments rather than as static records. Comparative case studies from 2025 show that digital twins can support predictive maintenance, structural monitoring, restoration planning, and visitor engagement, while also improving remote access and interpretive storytelling. In damaged or threatened sites, AI-assisted reconstruction from scans, photographs, and archival data can help specialists evaluate alternative restoration scenarios and preserve information that might otherwise be lost. This makes digital heritage technologies relevant not only to technical conservation, but also to cultural continuity and public memory across generations [6].

Yet restoration remains one of the most ethically sensitive areas of AI application. AI can help reconstruct forms, identify patterns, and simulate missing elements, but it cannot independently decide what is historically authentic, culturally legitimate, or appropriate to restore. Heritage conservation always involves interpretation, value judgement, and disciplinary responsibility. For this reason, AI should be treated as a powerful analytical and documentary partner in restoration, not as an autonomous authority over the past. In intergenerational terms, the goal is not simply to recreate what was lost, but to transmit cultural significance responsibly into the future [5].

An illustrative example of AI-supported heritage restoration is the Church of the Savior on Spilled Blood in St. Petersburg (Figure 2). Its frescoes constitute an important part of the monument’s historical and artistic heritage. Both the frescoes and the church itself were severely damaged during the siege of Leningrad, which began on September 8, 1941. Despite numerous efforts to preserve this heritage, a significant part of it was destroyed, and restoration work has continued for decades. In this context, computer vision and machine learning algorithms were used to assess the degree of damage to the frescoes in detail, making it possible to develop a more effective conservation and restoration strategy. Deep learning methods were also applied to analyse cracks and monitor their progression, significantly improving the accuracy of predicting the risk of further deterioration. Figure 2 presents the main stages of AI-assisted digital restoration, including image pre-processing, segmentation, defect detection, reconstruction of missing fragments, colour and texture correction, geometric adjustment, vectorization, and final output preparation [7].

Figure 2. AI-assisted heritage restoration workflow



Source: Author, 2026, adapted from Grace, Kovalev, and Voroshilova (2024).

7. Discussion: AI, Stewardship, and Co-Design Across Generations

Taken together, generative design, predictive modelling, and heritage restoration show that AI extends architecture's temporal reach. In design, it can reduce environmental impact before construction begins. In performance analysis, it helps anticipate how buildings and urban systems may function under changing conditions over time. In heritage contexts, it supports the preservation and reactivation of cultural memory for future generations. Although these domains are often examined separately, an intergenerational perspective reveals their underlying unity: each addresses architecture's responsibility not only to the present, but also to the future [2].

This broader perspective also reshapes the role of the architect. Rather than eliminating human agency, AI increases the importance of curation, critical evaluation, and ethical mediation. The literature consistently shows that algorithmic efficiency cannot substitute for cultural judgement. A technically optimized building may still fail socially, just as a persuasive digital reconstruction may remain historically misleading. The key question, therefore, is not whether AI can produce architectural solutions, but whether it can support forms of design and preservation that remain accountable to environmental limits, social needs, and cultural inheritance. Current research suggests that the most productive model is collaborative rather than substitutional: AI is most valuable when it reinforces human stewardship instead of replacing it [2].

This relationship is summarized in Table 1, which compares the respective contributions of AI and human architects across dimensions central to intergenerational sustainability, including design generation, performance prediction, cultural interpretation, ethical responsibility, heritage restoration, and long-term stewardship. The comparison shows that AI significantly expands architectural capacity in analysis, simulation, and restoration, while human agency remains essential in interpretation, ethical judgement, and responsibility across time.

Table 1. Comparative Roles of AI and Human Agency in Intergenerational Architecture

Dimension	AI in Architecture	Human Agency in Architecture
Design generation	Rapidly generates and optimizes multiple low-impact design options based on performance criteria and project parameters.	Defines goals, selects meaningful alternatives, and ensures contextual and spatial quality.
Performance prediction	Models long-term energy use, climate response, occupancy patterns, and operational risks.	Interprets predictions, balances competing priorities, and makes final design decisions.
Cultural interpretation	Identifies patterns and reconstructs visual or formal relationships from available data.	Understands symbolism, identity, memory, and the cultural meaning of place.
Ethical responsibility	Supports decision-making but depends on data quality, algorithms, and human supervision.	Takes responsibility for fairness, inclusiveness, authenticity, and public value.
Heritage restoration	Assists with digital twins, damage detection, reconstruction of missing fragments, and conservation planning.	Determines what should be preserved, how authenticity is assessed, and how heritage is interpreted.
Long-term stewardship	Improves monitoring, predictive maintenance, and lifecycle analysis across buildings and sites.	Ensures that environmental, social, and cultural values are carried forward for future generations.

Source: Author, 2026.

8. Conclusion

Artificial intelligence is reshaping architecture through three powerful capabilities: the generation of low-impact design alternatives, the prediction of long-term building and urban performance, and the restoration of cultural heritage through data-rich digital methods. These capabilities are highly relevant to intergenerational sustainability because they allow architecture to address environmental burden, future resilience, and cultural continuity within a shared analytical framework. AI can help architects work more efficiently, test more scenarios, and preserve more information than traditional methods alone.

At the same time, the review shows that intergenerational sustainability cannot be delegated to machines. Questions of meaning, authenticity, responsibility, and public value remain human concerns. AI can optimize, predict, and reconstruct, but it cannot determine by itself what should endure, what should change, and what must be preserved for future generations. For that reason, the most productive future for architecture lies not in replacing architects with AI, but in building a responsible partnership in which computational intelligence supports long-term environmental and cultural stewardship.

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