Leveraging AI to Co-Create a Circular and Desirable Built Environment

van Laar, B.R.; Greco, A.; Remøy, H.T.; Gruis, V.H.; Hamida, M.B.

Publication date
2024

Document Version
Final published version

Published in
Amplify

Citation (APA)
van Laar, B. R., Greco, A., Remøy, H. T., Gruis, V. H., & Hamida, M. B. (2024). Leveraging AI to Co-Create a Circular and Desirable Built Environment. *Amplify* , *37*(11), 16-23.

LEVERAGING AI TO CREATE A CIRCULAR BUILT ENVIRONMENT

Authors

Brian van Laar, Angela Greco, Hilde Remøy,
Vincent Gruis, and Mohammad Hamida

The built environment plays a crucial role in the ongoing challenge of climate change, primarily through resource consumption, energy use, and contributions to greenhouse gas (GHG) emissions. As urbanization accelerates, the environmental footprint of construction and building operations has grown significantly. Currently, buildings account for 40% of the world's waste, 40% of material resource use, and 33% of human-induced emissions.[1]

To mitigate these impacts, adopting circular economy principles that focus on material reuse, recycling, and regeneration is essential to foster a sustainable, closed-loop system.[2] This approach stands in stark contrast to the traditional linear economy, which operates on a take-make-dispose model, leading to excessive waste and resource depletion. In a circular economy, materials are kept in use for as long as possible by recycling, reusing, and remanufacturing.[3]

Among circular economy strategies, adaptive building reuse stands out. This approach involves repurposing buildings to extend their lifespan, conserve embodied energy, and minimize demolition waste.[4] Adaptive reuse reduces GHG emissions while conserving natural resources and revitalizing communities.[5]

Far from a new concept, adaptive reuse has been practiced for centuries. The conversion of buildings from one use to another has occurred in various contexts, at different scales, throughout history.[6] For example, in the Netherlands, many canal houses have been adapted and reused multiple times due to various causes of obsolescence, including changes in building regulations, shifts in the housing market, or evolving urban needs such as the diminished demand for warehouses in city centers.

However, the decision-making process involved in adaptive reuse is fraught with complexity and uncertainty.[7] Causes include the inherently slow pace of such projects, the lack of participatory engagement, and the struggles stakeholders face in envisioning future scenarios.[8-10] The process is often prolonged as stakeholders navigate regulatory frameworks, technical constraints, and diverse community needs.[11]

> **AMONG CIRCULAR ECONOMY STRATEGIES, ADAPTIVE BUILDING REUSE STANDS OUT**

The absence of sufficient participatory engagement means that the voices of key stakeholders, such as residents and local businesses, are often underrepresented. This lack of involvement can exacerbate tensions and contribute to polarized views on the future, as various groups struggle to align their visions with what is possible.[12] The difficulty in predicting future environmental, social, and economic conditions further complicates consensus building, often leading to decisions that are less sustainable and less beneficial to the community.[13]

Too often, polarized and contradictory views crop up among stakeholders, and each group clings to its perspective, sometimes at the expense of others.[14] This can skew decisions toward one dominant view, neglecting the broader range of possibilities and the needs of other stakeholders.[15]

To overcome this polarization, it is crucial to visualize these contradictions and make them explicit during the decision-making process.[16] By bringing differing views to the forefront, stakeholders can better understand the implications of each perspective and work toward more balanced, inclusive solutions.

> **TOO OFTEN, POLARIZED & CONTRADICTORY VIEWS CROP UP AMONG STAKEHOLDERS**

AI is a powerful tool in this process. It can rapidly generate visual representations of adaptive reuse scenarios, enabling stakeholders to explore future conditions and see the potential effect of their decisions. The technology allows for a more collaborative approach, helping bridge the gap between opposing views and supporting the development of resilient, well-rounded adaptive reuse projects that are aligned with long-term community and environmental goals.

This article draws on the experience of Reincarnate, an EU-funded initiative aimed at increasing the use of construction and demolition waste while reducing buildings' CO2 emissions. We illustrate how an AI-driven, process-oriented approach to forward-looking co-creation can significantly enhance stakeholder engagement, enable viable adaptive reuse projects, and accelerate the transition to a circular built environment (see Figure 1).

CHALLENGES

Construction is often regarded as a conservative industry, marked by a reluctance to adopt new technologies and innovations. Its decision-making tends to be top-down and fragmented across stages, leaving little room for iteration or flexibility.[17] In the context of adaptive reuse, decision-making is predominantly driven by economic considerations, with insufficient emphasis on participatory engagement.[18]

Local residents and stakeholders are frequently informed only after an initial direction has already been chosen rather than being involved from the outset. The design process is often linear, with architects adhering to top-down directives from the client, restricting design flexibility and limiting stakeholder input. This approach leads to conflicts and misalignment during initial strategy development, often prompting decision makers to opt for demolition and new construction to avoid challenges.[19]

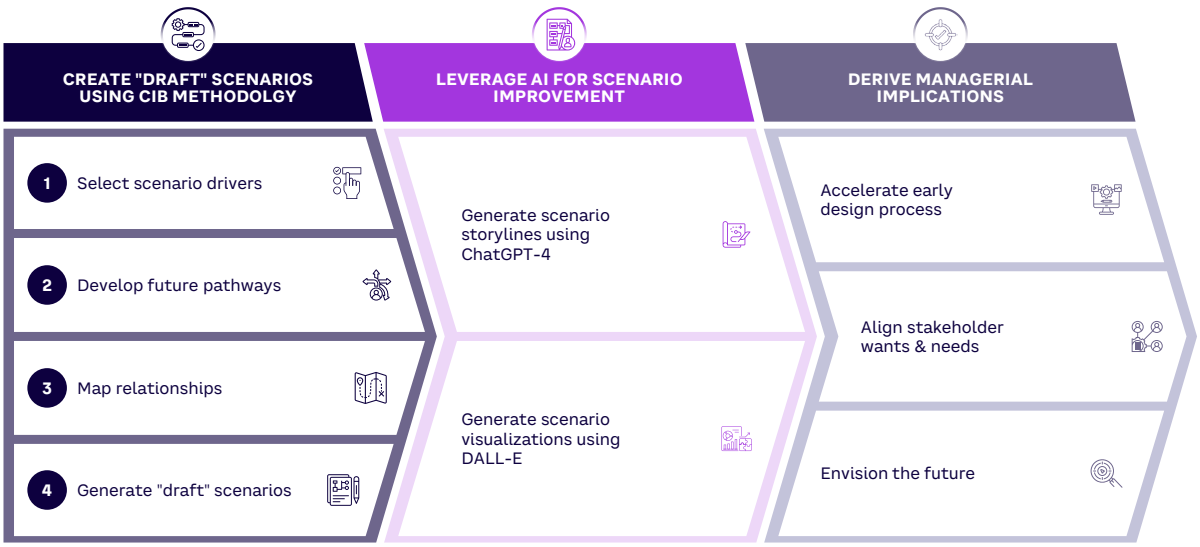

Figure 1. Summary of the research process

Their inherent complexities and uncertainties make adaptive reuse projects notorious for delays.[20] When strategizing collectively, we bring our own biases and tend to make choices based on established ways of working, following simple heuristics.[21] This can be a problem when decision-making involves complex and contradictory demands, as is the case of adaptive reuse projects.[22]

In construction projects, slow decision-making exacerbates the issue by driving a return to rigid, hierarchical structures, with the hope that this will streamline decisions. Paradoxically, it often makes the process even slower, as these structures fail to account for the nuanced (and often conflicting) requirements of complex projects. This rigidity ultimately hampers the ability to adapt effectively to specific project needs.

Overcoming these biases requires a shift toward collective, forward-looking co-creation in the decision-making process.[23] However, decision makers often struggle with this, particularly when long-term decisions have unforeseeable impacts.[24] The inability to envision future possibilities can lead to polarized views, resulting in decisions that disproportionately favor one perspective over others.[25]

Current approaches in the adaptive reuse decision-making literature tend to focus either on broad functional use or specific design options, which can limit decision effectiveness and quality.[26] Addressing this requires visualizing and explicitly acknowledging these contradictions, then exploring the wide range of future possibilities through collaborative action.[27]

> **GENAI OFFERS A FASTER, MORE SYSTEMATIC METHOD OF PRODUCING VISUAL & NARRATIVE OUTPUTS**

FUTURE-PROOFING ADAPTIVE REUSE

Scenario development addresses the challenges of adaptive reuse projects by providing a future-oriented perspective that assesses long-term sustainability and functionality. It allows stakeholders to consider various scenarios, which helps them anticipate shifts in environmental, social, and economic conditions and ensures that decisions are both adaptable and resilient. By highlighting the potential outcomes of various choices over a building's lifespan, scenario development fosters more sustainable and informed decision-making — crucial for projects that need to stay aligned with long-term community and environmental goals.

Traditionally, narrative and visual elements within scenarios have been crafted by local artists using techniques like visual harvesting, in which ideas are captured and represented in real time. This approach, although valuable for its human sensitivity and nuanced interpretation, can be time-consuming and reliant on artist availability and style.

Generative AI offers a faster, more systematic method of producing visual and narrative outputs. AI can incorporate a broader range of data and perspectives, ensuring consistency and reducing the risk of omitting contrasting scenarios that need to be considered. Rather than replacing the artistry and insight of handcrafted techniques, AI enhances the process, enabling a more inclusive representation of ideas and reducing the possibility of bias or oversight in the selection of information.[28]

This integration of scenario development and advanced visualization aligns well with the need for an iterative, flexible approach in adaptive reuse projects. By shifting toward forward-looking co-creation, decision makers can better navigate the complexities and uncertainties inherent in these projects, leading to decisions that are more inclusive, sustainable, and responsive (refer back to Figure 1).

LEVERAGING AI TO ACCELERATE ADAPTIVE REUSE DECISION-MAKING

AI has the potential to address challenges in adaptive reuse decision-making. As part of the Reincarnate project, we created desirable futures for the circular adaptive reuse of buildings through a series of scenarios. These scenarios contribute to Reincarnate's broader goal of developing technical and social strategies to create opportunities for buildings, construction products, and materials.

The scenario development process included a novel approach that combined traditional scenario methodology (cross-impact balance analysis) with participatory scenario-planning workshops. We used AI tools to collaboratively develop narrative and visual elements with stakeholders, which allowed us to better understand their benefits and how they can accelerate adaptive reuse decision-making.

The outcomes include 15 detailed scenarios that can guide stakeholders in exploring future pathways for circular adaptive reuse, with practical implications for policy and project implementation. These are "big picture" scenarios for adaptive reuse that represent hypothetical possibilities and are not related to specific projects.

Through this approach, we were able to consider a wide range of parameters that would be difficult to combine and analyze in a handcrafted scenario, ensuring a more comprehensive, data-driven outcome. This resulted in scenario scorecards like the one shown in Figure 2.

For 15 descriptors (e.g., political and community support, cost), three potential variants were drawn up:

1. **Strong** — descriptor's objective was reached (happy green emoticon)
2. **Medium** — descriptor's objective was partially reached (neutral yellow emoticon)
3. **Weak** — descriptor's objective was not reached (sad red emoticon)

The relationships between these descriptor variants were mapped during a workshop with adaptive reuse experts. An algorithm calculated consistent combinations of variants, which served as draft scenarios. For 15 consistent draft scenarios, ChatGPT-4 generated storylines based on the descriptions of the variants. DALL-E, an extension in ChatGPT-4, generated images from these textual descriptions.

SCENARIO NO. 24

Political & community support	Supportive hesitation
Cost	Moderately costly
Local economy	Local economic engine
Market potential	Sufficient market potential
Social impact	Socially limited
Accessibility	Inaccessible
Building technology	Technologically adequate
Environmental impact	Environmentally unfriendly
Indoor environmental quality	Cold & loud
Rules & regulations	Regulatory challenges
Flexibility & adaptability	Flexible & adaptable
Quality & durability	Strong & durable
Physical characteristics	Spacious & versatile
Architectural value	Architectural beauty
Historic & cultural value	Preserving history

NAME SCENARIO: DIAMOND IN THE ROUGH

In a scenario where an iconic but no longer used building on the outskirts of the old city center is preparing for transformation, stakeholders navigate a landscape of cautious support and economic efficiency. Despite the hesitations of some key stakeholders **(supportive hesitation)** and the moderate costs **(moderately costly)** that slightly exceed the budget, this project promises to become a **(local economic engine)**, with an undeniable positive impact on the local economy. Creating jobs, stimulating local businesses, and improving public amenities are just some of the benefits the transformation will bring. With **(sufficient market potential)** located in a diverse and dynamic environment, the building is seen as attractive to a wide range of buyers and tenants, despite some financial risks. However, the project also faces its challenges. It confronts significant obstacles in terms of social impact **(socially limited)**, accessibility **(inaccessibility)**, and environmental impact **(environmentally unfriendly)**, with the current state described as "limited social," "limited accessibility," and "environmentally unfriendly." These shortcomings in the indoor environment **(cold & loud)**, technological limitations **(technologically adequate)**, and a strict regulatory environment **(regulatory challenges)** require a thoughtful approach to achieve the desired transformation. The heart of the transformation lies in the **(flexible & adaptable)** nature of the building, supported by **(strong & durable)** and spacious physical features **(spacious & versatile)** that enable the building to be redeveloped into a flexible, open, and multifunctional space. The architectural **(architectural beauty)** and historical value **(preserving history)** of the property is not only maintained but also celebrated, enriching the building and its surroundings. This transformation is driven by the vacancy of the building, the value of the location, and the desire to preserve a historical monument. With a project duration of approximately 3-4 years, the building will be transformed into a vibrant, multifunctional space that combines housing with other uses, making it accessible to the public and a valuable asset to the surrounding community. Inspiration for this project can be found in similar successful transformations, such as the Koepelgevangenis in Arnhem, the Werkspoorfabriek in Utrecht, and the Bijlmerbajes in Amsterdam. These examples show that with the right approach, vision, and collaboration, old buildings can be revitalized, ensuring they are preserved for future generations while also contributing to the livability and dynamism of urban environments.

Figure 2. Scenario scorecard created with DALL-E and ChatGPT-4

The scenario storylines served as input, accompanied by the prompt: "Create an image of an adaptive reuse scenario based on the scenario storyline above." DALL-E transformed the prompts into visual outputs, but refinement was needed to ensure the visualizations aligned more closely with specific expectations. Two images were generated: one from outside of the building and one from inside the building looking out.

The sections below describe the managerial implications of using AI tools in the early stages of adaptive reuse decision-making and how they can benefit practitioners.

ACCELERATING THE EARLY DESIGN PROCESS

Using AI visualization tools early in the design process has profound managerial implications. The traditional design process is lengthy and predominantly bottom-up: architects develop proposals for stakeholders to review and comment on. This sequential approach leads to delays and limited stakeholder engagement in the initial stages. By integrating AI visualization tools, stakeholders can be involved at the outset, collaboratively visualizing potential futures alongside architects.

This shift enables faster, more inclusive prototyping, allowing for iterative cycles in which scenarios are quickly explored, refined, or excluded based on collective input. The design process becomes more dynamic and responsive, reducing the time needed to arrive at an initial draft.

ALIGNING STAKEHOLDER WANTS & NEEDS

AI visualization tools can help align stakeholder wants and needs while enhancing their participation. In traditional design, differing stakeholder objectives lead to conflicting demands, making it hard to reach a consensus. AI visualization allows stakeholders to collaboratively visualize potential pathways, integrating these contradictory objectives in real time.

This approach accelerates the decision-making process and helps stakeholders see the tangible impact of their preferences and compromises, fostering a more inclusive and participatory environment. When integrated outcomes can be viewed early in the design process, managers can quickly identify and address potential conflicts, ensuring that the final design better reflects the collective vision of all parties.

ENVISIONING THE FUTURE

Traditionally, skilled architects produce renderings that resemble the final outcome, a time-consuming process that requires specialized expertise. Moreover, capturing the parametric complexity of early design stages is usually challenging. AI visualization tools streamline this process by making abstract concepts more tangible, allowing stakeholders to quickly grasp the potential impact of a scenario and reducing the need for multiple iterations.

Faster exclusion of unviable options helps surface the contradictions inherent in the design process. By making these tensions more visible and quantifiable, AI helps overcome human biases that often cloud judgment during abstract design phases. It acts as a heuristic tool, guiding stakeholders toward more concrete and balanced decisions, leading to more informed and efficient outcomes. These benefits are particularly valuable in complex projects where competing objectives must be balanced. AI enables a clearer understanding of trade-offs, helping managers "put their finger" on the magnitude of the contradictions and address them quickly and effectively.

LOOKING AHEAD

AI offers exciting opportunities to accelerate design processes and align stakeholder needs. It has the potential to enhance efficiency, empower individuals without traditional artistic skills, and drive sustainable innovation.

AI visualization tools do have drawbacks, including diminishing the role of human creativity in the early design process by giving non-creative individuals the ability to develop designs. It's important to develop AI-generated visualizations in collaboration with local artists or architects to ensure that human insight and creativity are maintained rather than replaced.

AI also contributes to the IT sector's increasing climate impact; the sector currently consumes nearly 10% of the world's energy.[29] In the project described above, a digital-first approach was adopted, using AI to visualize desirable futures for

adaptive reuse. This approach leverages digital assets as the primary medium for experimentation and innovation, allowing firms to design, iterate, and optimize net zero solutions in the digital space before implementing them physically, which lowers emissions compared to traditional processes.[30]

We believe the future of AI lies in a digital-first approach, in which AI tools enhance decision-making at both management and individual levels. In particular, AI helps decision makers better understand circular scenarios, and it does so in a more iterative and participatory manner.

AI visualizations can inspire individuals by showing them a future they want to be part of (or one they want to avoid), encouraging them to embrace sustainable practices. Social barriers to adopting a circular economy, including resistance to change and perceptions of inconvenience, can be overcome by AI-powered visualizations that clearly represent the benefits of circular strategies.

By demonstrating how these approaches can reduce environmental impact, revitalize communities, and improve quality of life, AI can motivate individuals to embrace sustainable practices like adaptive reuse, making the transition to a circular economy achievable and personally rewarding.

REFERENCES

1 Layke, Jennifer, et al. "Accelerating Building Efficiency: Eight Actions for Urban Leaders." World Resources Institute, 11 May 2016.

2 Tseng, Ming-Lang, et al. "Circular Economy Enables Sustainable Consumption and Production in Multi-Level Supply Chain System." *Resources, Conservation and Recycling*, Vol. 154, March 2020.

3 Tseng et al. (see 2).

4 Foster, Gillian. "Circular Economy Strategies for Adaptive Reuse of Cultural Heritage Buildings to Reduce Environmental Impacts." *Resources, Conservation and Recycling*, Vol. 152, January 2020.

5 Foster (see 4).

6 Lanz, Francesca, and John Pendlebury. "Adaptive Reuse: A Critical Review." *The Journal of Architecture*, Vol. 27, No. 2-3, September 2022.

7 Yung, Esther H.K., and Edwin H.W. Chan. "Implementation Challenges to the Adaptive Reuse of Heritage Buildings: Towards the Goals of Sustainable, Low Carbon Cities." *Habitat International*, Vol. 36, No. 3, July 2012.

8 Eray, Ekin, Benjamin Sanchez, and Carl Haas. "Usage of Interface Management System in Adaptive Reuse of Buildings." *Buildings*, Vol. 9, No. 5, April 2019.

9 Yung and Chan (see 7).

10 Langston, Craig, Esther Hui-Kwan Yung, and Edwin Hon-Won Chan. "The Application of ARP Modelling to Adaptive Reuse Projects in Hong Kong." *Habitat International*, Vol. 40, October 2013.

11 Conejos, Sheila, et al. "Governance of Heritage Buildings: Australian Regulatory Barriers to Adaptive Reuse." *Building Research & Information*, Vol. 44, No. 5-6, April 2016.

12 Verloo, Nanke. "Ignoring People: The Micro-Politics of Misrecognition in Participatory Governance." *Environment and Planning C: Politics and Space*, Vol. 41, No. 7, June 2023.

13 Greco, Angela, Rikke Kristine Nielsen, and Manon Eikelenboom. "Fostering Sustainability and Entrepreneurship Through Action Research: The Role of Value Reciprocity and Impact Temporality." In *De Gruyter Handbook of Sustainable Entrepreneurship Research,* edited by Gjalt de Jong et al. De Gruyter, 2023.

14 Aigwi, Itohan Esther, et al. "Characterisation of Adaptive Reuse Stakeholders and the Effectiveness of Collaborative Rationality Towards Building Resilient Urban Areas." *Systemic Practice and Action Research*, Vol. 34, No. 2, April 2021.

15 Aigwi et al. (see 14).

16 Greco, Angela, et al. "Media Review: Barbie and Ken — Staging Paradoxes to Bridge Polarization." *Organization Studies*, 20 August 2024.

17 Nawi, Mohd Nasrun Mohd, Nazim Baluch, and Ahmad Yusni Bahauddin. "Impact of Fragmentation Issue in Construction Industry: An Overview." *MATEC Web of Conferences*, Vol. 15, August 2014.

18 Yung and Chan (see 7).

[19] Bullen, Peter A., and Peter E.D. Love. "The Rhetoric of Adaptive Reuse or Reality of Demolition: Views from the Field." *Cities*, Vol. 27, No. 4, August 2010.

[20] Eray et al. (see 8).

[21] Greco, Angela, Thomas B. Long, and Gjalt de Jong. "Identity Reflexivity: A Framework of Heuristics for Strategy Change in Hybrid Organizations." *Management Decision*, Vol. 59, No. 7, June 2021.

[22] van Laar, Brian, et al. "What Matters When? — An Integrative Literature Review on Decision Criteria in Different Stages of the Adaptive Reuse Process." *Developments in the Built Environment*, Vol. 18, April 2024.

[23] Sharma, Garima, et al. "Cocreating Forward: How Researchers and Managers Can Address Problems Together." *Academy of Management Learning & Education*, Vol. 21, No. 3, September 2022.

[24] Greco et al. (see 13).

[25] Aigwi et al. (see 14).

[26] van Laar et al. (see 22).

[27] Greco et al. (see 16).

[28] Verheijden, Mathias Peter, and Mathias Funk. "Collaborative Diffusion: Boosting Designerly Co-Creation with Generative AI." *CHI EA '23: Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, 2023.

[29] Andersen, Allan Dahl, et al. "On Digitalization and Sustainability Transitions." *Environmental Innovation and Societal Transitions*, Vol. 41, October 2021.

[30] Falcke, Lukas, et al. "Digital Sustainability Strategies: Digitally Enabled and Digital-First Innovation for Net Zero." *Academy of Management Perspectives*, 18 March 2024.

About the authors

Brian van Laar is a PhD researcher for the Faculty of Architecture and the Built Environment, Delft University of Technology (TU Delft), the Netherlands, conducting research on decision-making for the building adaptive reuse process. Mr. van Laar has a background in urban engineering and urban economics. He can be reached at B.R.vanLaar@tudelft.nl.

Angela Greco is is Assistant Professor in Innovation Management for the Faculty of Architecture, Delft University of Technology (TU Delft), the Netherlands, with a background in social science and architecture, dedicated to contributing to a sustainable built environment. Her research interests focus on accelerating innovation processes through business model innovation, navigating paradoxes in sustainability, and scaling sustainability-driven innovations. Dr. Greco can be reached at A.Greco@tudelft.nl.

Hilde Remøy is Associate Professor at Delft University of Technology (TU Delft), the Netherlands, researching building transformation as a sustainable real estate strategy, with an emphasis on future use value, energy efficiency, and circular transformation. Dr. Remøy can be reached at H.T.Remoy@tudelft.nl.

Vincent Gruis is Professor in Housing Management at Delft University of Technology (TU Delft), the Netherlands. He is currently researching organizational strategies in housing management, with a focus on how housing managers and developers can adapt their portfolios and operations to meet societal needs, emphasizing sustainability, innovation, and the practical application of business management approaches. Dr. Gruis can be reached at V.H.Gruis@tudelft.nl.

Mohammad Hamida is a PhD researcher at Delft University of Technology (TU Delft), the Netherlands. He is currently developing an integrated framework that incorporates the principles of a circular built environment and sustainable building adaptation, aimed at enabling the construction industry and property market to meet future demands amidst economic and environmental changes. He can be reached at M.B.Hamida@tudelft.nl.