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A participatory approach

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Towards desirable futures for the circular adaptive reuse of buildings: A participatory approach

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ABSTRACT

Adaptive reuse of buildings offers a sustainable strategy for reducing global CO2 emissions by repurposing existing structures, conserving resources, reducing the need to extract new materials, and minimizing waste. However, the decision-making process in adaptive reuse projects is often complex, involving conflicting criteria and diverse stakeholders. Current approaches tend to polarize alternatives, focusing either on broad functional use or specific design options, which can limit decision effectiveness and quality. This study addresses these challenges by developing a participatory mixed-methods approach that integrates Cross-Impact Balance (CIB) analysis with creative scenario-building techniques, including generative AI and participatory workshops. This approach balances the extremes of current decision-making processes, offering a more comprehensive overview of desirable futures for decision-makers. The methodology was applied to create 15 “big picture” circular adaptive reuse scenarios, each incorporating circular building adaptability (CBA) strategies, and enriched with AI generated narratives and visualizations. These scenarios provide stakeholders with a nuanced understanding of potential future pathways, enhancing decision-making processes. This mixed-method approach demonstrates the potential of participatory CIB scenario development in advancing circularity, offering a valuable tool for navigating the complexities of adaptive reuse decision-making.

1. Introduction

The built environment is a major contributor to global CO2 emissions, resource depletion and waste, primarily due to the construction, operation, and demolition of buildings (Ali et al., 2020). Adaptive reuse, which involves repurposing existing structures for new uses (Shahi et al., 2020), helps to conserve resources, reduces waste, and lowers emissions by extending the life of buildings (Yung & Chan, 2012). Additionally, adaptive reuse can be socially beneficial, preserving historic buildings and revitalizing communities (Bassal & Khalifa, 2022). Nevertheless, the implementation of adaptive reuse projects is faced with uncertainty and complexity (Bassindale, 2020; Yung & Chan, 2012). Adaptive reuse projects are inherently complex due to the unpredictability of the quality of existing structures, which can hide damages or hazardous materials only discovered during on-site building interventions (Langston, 2011), leading to unexpected costs and delays (Eray et al., 2019). Integrating modern functionalities and meeting current building codes in older structures adds further technical challenges (Conejos et al., 2016; Mohamad et al., 2023). Balancing the preservation of historical and architectural value with contemporary needs also complicates these projects (Augustiniok et al., 2023). Additionally, uncertain market trends and shifting stakeholder priorities contribute to the complexity of decision-making (Bottero et al., 2019). A significant challenge is the arbitrary selection of new functions for buildings, often due to a lack of a clear decision-making methodology (Mısırlısoy & Günçe, 2016), which must consider a wide range of factors including location, heritage significance, market trends, and community needs (Bullen & Love, 2011).

To address the complexity and uncertainty inherent in the adaptive reuse decision-making process, various tools and methods have been proposed. Multi-criteria decision-making (MCDM) models have gained significant popularity in recent years for evaluating adaptive reuse projects (Nadkarni & Puthuvayi, 2020). These models offer a structured approach to assess and compare alternative solutions by considering multiple criteria (Mardani et al., 2015). In most multi-criteria decision-making models for adaptive reuse, the assessed alternatives are either very general, focusing solely on functional use, or very specific, examining detailed design options (van Laar et al., 2024). For example,

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there is a need for a broader overview of options in the decision-making process, providing decision-makers with a comprehensive understanding of the possibilities when pursuing adaptive reuse (van Laar et al., 2024). This focus on polarized alternatives may struggle to fully address broader goals and diverse stakeholder needs. Exploring methods and tools that encourage a broader range of desirable futures could help overcome these limitations. These futures, ideally, would not only emphasize desirable traits like sustainability, resource efficiency, and inclusivity, but also emerge through active participation, making them more comprehensive and reflective of stakeholder priorities. Additionally, current adaptive reuse projects often lack circularity strategies beyond merely reusing the building itself (Foster & Kreinin, 2020; Ikiz Kaya et al., 2021). Moreover, adaptive reuse projects demand enhanced participatory engagement throughout the decision-making process, including the identification of solutions and alternatives (Moosavi & Browne, 2021; Ragheb, 2021). This highlights the need for more comprehensive intervention scenarios that integrate circular (design) strategies into adaptive reuse projects through active participation (van Laar et al., 2024).

Scenarios provide valuable input for decision-making in adaptive reuse projects by offering comprehensive, future-oriented insights essential for evaluating long-term sustainability and functionality (Bottero et al., 2022). By integrating scenarios, decision-makers can systematically explore various future states and potential changes in environmental, social, and economic conditions (Elsawah et al., 2020). This foresight allows stakeholders to evaluate how different reuse options might perform under multiple future uncertainties, ensuring decisions are robust and flexible (Weimer-Jehle, 2023). Scenarios help to understand the implications of each choice over the building's lifespan, supporting more sustainable and informed decision-making processes (Kamari et al., 2018). This is crucial for adaptive reuse projects, where outcomes must be resilient to future changes and aligned with long-term community and environmental goals (Tam & Hao, 2019).

Scenario development methods can be categorized into quantitative and qualitative approaches. Quantitative methods, while capable of achieving a high level of precision, often involve complex mathematical processes that hinder stakeholder involvement (Weimer-Jehle, 2006). This precision can falsely imply a high degree of certainty (Welsh et al., 2024), producing scenarios that simply extend past trends. Consequently, the effectiveness of quantitative methods tends to diminish over longer timeframes (Amer et al., 2013). Conversely, while qualitative methods are often favored for addressing complex issues due to their ability to capture nuanced, context-specific insights, they can be limited when it comes to computing a large number of variables and incorporating analytical considerations. For instance, Intuitive Logics (IL), a popular qualitative technique, constructs scenarios based on only two main uncertainties (Rowe et al., 2017), potentially overlooking crucial factors and oversimplifying complex systems (Weimer-Jehle et al., 2020).

To address the limitations of both quantitative and qualitative methods, mixed-methods approaches are beneficial. Combining these methods can yield more cohesive and integrated scenarios (Almalki, 2016). An example of a mixed-method approach is cross-impact balance (CIB) analysis (Weimer-Jehle, 2006), a systematic yet qualitative method used for socio-technical scenario development. Cross Impact Balance (CIB) analysis is a flexible, systematic method used to explore the interactions and plausible developments within complex systems by leveraging expert judgments on systemic interactions (Weimer-Jehle, 2023). Combining CIB with other qualitative and creative methods, such as participatory workshops, enhances the robustness and creativity of scenario development (Schweizer, 2020). Participatory workshops engage diverse stakeholders, fostering inclusive discussions and capturing a wide array of perspectives and knowledge, which is critical for comprehensive systems analysis (Johnson et al., 2012). This integration facilitates the generation of innovative, non-linear scenarios that are more reflective of real-world complexities (Nygrén, 2019). Additionally, incorporating participatory methods in CIB processes ensures that the scenarios are grounded in practical, stakeholder-driven knowledge, making them more relevant and actionable (Reed et al., 2013). This combination not only improves the analytical rigor of the scenarios but also enhances stakeholder engagement and the practical applicability of the findings (Weimer-Jehle, 2006). While, CIB has been used in a participatory manner in other research fields like climate change research (Schweizer, 2020), and transportation research (Tori et al., 2023), to the best of our knowledge there have been no studies applying a participatory CIB approach to the field of adaptive reuse. By incorporating participatory methods into CIB, it becomes possible to move beyond the limited, polarized alternatives often seen in previous literature (van Laar et al., 2024), providing a broad range of desirable futures that are collaboratively developed and widely supported by stakeholders.

The aim of this research was to develop a participatory methodology that merges CIB analysis with creative and qualitative scenario-building techniques using scenario workshops. Our research question is: how can cross-impact balance analysis be integrated with scenario development workshops to collaboratively develop circular building adaptive reuse scenarios?

The outcomes of this study are twofold. First, it shows how scenario analysis can profit from participatory workshops and other creative and qualitative scenario-building techniques, by showcasing a new collaborative and innovative approach. Secondly, it provides an overview of comprehensive circular adaptive reuse scenarios that integrate circularity strategies, which give stakeholders of adaptive reuse projects a better understanding of the possibilities when pursuing desirable futures for adaptive reuse. In practice, policymakers can refer to these scenarios to amend existing adaptive reuse policies, while practitioners can utilize them as a knowledge-based informative synthesis for arriving at practical and futureproof circular reuse projects.

This article is organized as follows: Section 2 provides a brief literature review on scenario building within the built environment, focusing on CIB analysis and scenario workshops. Section 3 details the methodology, combining CIB, participatory workshops, and various creative and qualitative scenario-building techniques. Section 4 showcases the application of this methodology. Section 5 explores the potential implications of our approach, and Section 6 concludes with final remarks and suggestions for future research.

2. Context and background literature

2.1. Circular economy in the built environment

The circular economy represents a transformative framework for addressing resource depletion, waste generation, and environmental degradation by shifting from a linear "take-make-dispose" model to a regenerative system rooted in reuse, recycling, and resource efficiency (Ghisellini et al., 2018; Kirchherr et al., 2017). Central to this concept is the aim to decouple economic growth from resource consumption, promoting closed-loop systems that minimize waste and maximize the value of materials across their lifecycle (Merli et al., 2018). In the built environment, the circular economy offers significant potential to address pressing challenges, as the construction and demolition sector remains a major contributor to carbon emissions, resource depletion, and waste generation (Joensuu et al., 2020). Barriers to implementing circular solutions in this sector include regulatory hurdles (Charef et al., 2021), fragmented supply chains (Al Jaber et al., 2023; Charef et al., 2021), and limited adoption of circular design principles, such as design for disassembly or the use of material passports (Adams et al., 2017). Additionally, financial incentives often favor new construction over reuse (Ghisellini et al., 2018), and the lack of standardized methodologies to measure and evaluate circularity complicates decision-making (Corona et al., 2019). Despite these challenges, opportunities are plentiful, including the integration of digital tools like Building Information

Modeling (BIM) (Copeland & Bilec, 2020) and material tracking systems to enhance transparency (Movaffaghi & Yitmen, 2023), as well as policies promoting reuse (Ikiz Kaya et al., 2021), and the development of circular business models (Geissdoerfer et al., 2018).

A promising circular strategy within the building industry is adaptive reuse, defined as “the process of extending the useful life of historic, old, obsolete, and derelict buildings, by seeking to maximize the reuse and retention of existing structures and fabrics” (Shahi et al., 2020). Adaptive reuse directly supports circular economy principles by preserving embodied energy, reducing the need for raw materials, and preventing demolition waste (Foster, 2020). Beyond environmental benefits, it offers social and economic advantages, such as revitalizing urban areas, preserving architectural heritage, and creating jobs (Bullen & Love, 2011). However, current adaptive reuse practices often prioritize financial returns (Della Spina et al., 2023), or focus on heritage buildings (Arfa et al., 2022), neglecting broader circularity strategies such as repurposing components or using flexible design principles (Ikiz Kaya et al., 2021). Regulatory hurdles and high initial costs further complicate these efforts (Yung & Chan, 2012), while the lack of a standardized framework for evaluating and planning reuse strategies leaves decision-makers reliant on narrow criteria and uncertain outcomes (Foster, 2020). A critical barrier is the difficulty in addressing the inherent complexity and uncertainty of adaptive reuse projects, particularly in predicting how various environmental, social, and economic factors might interact in the future (Tam & Hao, 2019). This uncertainty underscores the need for structured tools and methods, such as scenarios, to navigate these complexities and envision pathways toward circularity in the built environment (Foster, 2020).

2.2. Scenario development

The use of scenarios in the built environment, especially within adaptive reuse (Bottero et al., 2022), has become a crucial tool for forecasting, planning, and decision-making, enabling engagement with complex and uncertain futures (Machiels et al., 2023). Scenarios, which are coherent, consistent, and plausible descriptions of potential future trajectories (Heugens & van Oosterhout, 2001), typically fall into three types: exploratory, predictive, and normative (van Notten et al., 2003). Exploratory scenarios explore a range of possible futures based on varying assumptions about key factors, aiding stakeholders in visualizing potential outcomes (van Notten et al., 2003). Predictive scenarios focus on forecasting the most likely future based on current trends, offering a probabilistic outlook (van Notten et al., 2003). Normative scenarios, however, are prescriptive, outlining pathways to achieve specific strategic goals or desired outcomes (van Notten et al., 2003). This approach is particularly beneficial for decision-making in adaptive reuse, where aligning decisions with broader sustainability objectives or community values is critical (Gassner & Steinmüller, 2018). Normative scenarios can be enriched with narrative elements, transforming them into normative narrative scenarios that are both inspiring and actionable, providing a clear roadmap for collective action and stakeholder alignment (Gassner & Steinmüller, 2018). To develop these scenarios, various methods can be employed; quantitative, qualitative, or mixed. Quantitative methods, while offering precision through clear assumptions and numerical results, can be complex and less accessible to those outside the process (Alcamo, 2008; Weimer-Jehle, 2006). Qualitative methods, in contrast, are designed to encourage broad thinking among stakeholders, though they may oversimplify complex systems (Alcamo, 2008; Weimer-Jehle, 2006). A mixed-method approach, combining both quantitative and qualitative techniques, is often the most effective for complex challenges, as it integrates technical data with stakeholder input (Baker et al., 2007; Mallampalli et al., 2016; Symstad et al., 2017), fostering comprehensive discussions about future possibilities (Urueña, 2019).

2.3. Cross-impact balance analysis

Semi-quantitative scenario methods, such as the cross-impact balance (CIB) method, are particularly well-suited for modelling integrative and holistic scenarios that strive to capture the overall picture accurately (Lazurko et al., 2023). The CIB method employs systems theory to generate internally consistent narrative scenarios based on a network of interacting drivers of change (Weimer-Jehle, 2006; Weimer-Jehle et al., 2016). Recognized as a mixed-method approach, CIB uses formal logic to structure both quantitative and qualitative inputs (Weimer-Jehle, 2023). Although grounded in systems thinking, which differs fundamentally from the positivistic approach often associated with statistical methods, CIB does not require probability assessments (Weimer-Jehle, 2006). It is distinguished by its transparency in calculations and outputs, making it accessible even to users without mathematical training (Weimer-Jehle, 2006).

A central element of CIB analysis is the identification of descriptors, which are key variables that define the system under study. Descriptors represent the critical factors or dimensions influencing the system, such as economic trends, technological developments, or social behaviors (Weimer-Jehle, 2023). Each descriptor is further detailed by specifying a range of possible variants, which are discrete, qualitative or quantitative states that the descriptor can assume. These variants are essential for structuring the scenarios and serve as building blocks for exploring system dynamics. The relationships between descriptors and their variants are captured in the cross-impact matrix, which forms the analytical core of CIB. The matrix records the influence each variant has on the others using an ordinal scale that represents the direction and strength of their interactions (e.g., strong positive, weak negative, or neutral impact). These relationships reflect the systemic interdependencies and potential feedback loops within the system (Weimer-Jehle, 2023).

Despite its strengths, CIB does have some challenges. The method depends on expert input to build the cross-impact matrix, which means the process can sometimes be influenced by subjective opinions or limited perspectives (Weimer-Jehle, 2023). The results also rely heavily on choosing and defining the right descriptors, so missing key factors or unclear definitions can weaken the analysis (Weimer-Jehle, 2023). For larger systems, the cross-impact matrix can become increasingly complex and harder to manage, which may make the process less practical (Weimer-Jehle, 2023). Another drawback is that CIB is static, meaning that it doesn’t account for how relationships between factors might change over time, limiting its ability to model dynamic systems (Weimer-Jehle, 2006).

The primary outcome of a CIB analysis is the identification of internally consistent scenarios, which is particularly useful in addressing multivariate problems characterized by numerous factors that can combine into millions of theoretically possible scenarios (Schweizer & Kurniawan, 2016). Internal consistency ensures that the scenarios developed through CIB are composed of mutually supportive assumptions, free of contradictory elements (Weimer-Jehle, 2006). CIB enhances scenario legitimacy and scientific credibility by maintaining transparency and flexibility in the analytical assumptions used throughout the process (Schweizer, 2020). Fundamentally, CIB analysis involves collecting qualitative information on "cross-impacts," or the influence relationships between scenario factors, and coding these relationships using an ordinal scale (Weimer-Jehle, 2023). A simple balance algorithm, supported by software, is then applied to determine which system developments form self-stabilizing trend networks, thereby identifying consistent scenarios (Weimer-Jehle, 2023). The resulting scenarios represent combinations of how different variables may unfold in a logically consistent manner.

Initially introduced in the field of technological forecasting, CIB has been utilized in over 100 studies across a range of disciplines, including energy transitions, climate change research, and transportation research. (Pregger et al., 2020; Tori et al., 2023; Weimer-Jehle, 2023; Weimer-Jehle et al., 2016). Its applications are now expanding to encompass a broader range of applications like: policy processes (Kosow et al., 2021; Stankov et al., 2021), and Social-Ecological Systems (Lazurko et al., 2023). While the uncertainty and complexity of adaptive reuse projects make them well-suited for the Cross-Impact Balance (CIB) methodology (Weimer-Jehle, 2023; Yung & Chan, 2012), no studies have yet applied this approach specifically in the context of adaptive reuse. CIB can be effectively complemented with other methods for scenario development, as recommended by Weimer-Jehle et al. (2020). The outcome of CIB analysis is a set of logically combinable factors that can serve as the foundation for structuring scenario storylines (Tori et al., 2023). Although additional efforts are needed to enhance these scenarios for effective communication, such as through creative workshops to develop narratives and visuals (Lyons et al., 2021; Tori et al., 2023), CIB remains particularly well-suited for participatory settings due to the transparency of the assumptions made throughout the process (Weimer-Jehle, 2023), and its ease in incorporating expert knowledge (Stankov et al., 2021).

2.4. Enriching CIB with participatory and integrative methods

Participatory scenario modelling has emerged as a powerful approach for structuring transdisciplinary research processes, where models are co-produced through active collaboration with stakeholders (Andreotti et al., 2020; Schmidt & Pröpper, 2017; Voinov et al., 2018). The primary objective of these processes extends beyond merely producing structured models; it aims to mobilize knowledge in ways that drive societal impact and foster meaningful learning among both scientists and participants (Smetschka & Gaube, 2020). Scenario workshops, central to this approach, have been shown to enhance social learning and empower participants' future-oriented thinking (Nygrén, 2019). However, these workshops are often resource-intensive and susceptible to biases arising from group thinking (D'Eon et al., 2008; Mougenot et al., 2017). To mitigate these biases, integrating formalized scenario-building methods can provide quantitative outputs that enhance the scientific validity and consistency of scenarios (Blass, 2003; Ernst et al., 2018). Furthermore, maintaining a consistent group of stakeholders throughout the process is crucial for fostering ownership and ensuring commitment to the outcomes (Leask et al., 2019).

The Cross-Impact Balance (CIB) methodology has been effectively integrated with participatory workshops in several studies (Kosow et al., 2022; Pregger et al., 2020; Stankov et al., 2021; Tori et al., 2023). While greater participatory involvement enhances the diversity of perspectives, it also presents challenges related to time and resource constraints. Integrating participatory involvement at different stages of the CIB methodology requires careful balancing of time, quality, and engagement levels (Weimer-Jehle, 2023). Given the complexity and breadth of the CIB methodology, some steps are better suited to participatory engagement than others. Traditionally, descriptor and variant selection within CIB has been managed internally by research teams (Tori et al., 2023; Weimer-Jehle, 2023); however, the Delphi method has proven effective in systematizing descriptor selection (Tori et al., 2023). Delphi is a facilitation technique used to achieve consensus among a group of experts by conducting a series of structured questionnaires or rounds (Nowack et al., 2011). Despite its strengths, the Delphi method often limits the incorporation of unconventional or unexpected factors of uncertainty (Tori et al., 2023). Therefore, it can be advantageous to adopt a more flexible approach, using a Delphi questionnaire to structure descriptors while avoiding rigid adherence, thereby encouraging more divergent thinking (Soria-Lara et al., 2021). For eliciting cross-impact data, participatory workshops are more frequently employed due to their capacity for interdisciplinary system reflection (Weimer-Jehle, 2023), with an optimal group size of 8–13 participants recommended to balance groupthink risks and socialization efforts (Weimer-Jehle, 2023).

The use of narrative and visual elements in participatory scenario development has been explored extensively (Foran et al., 2013; Upham et al., 2016; Vervoort et al., 2010). Narrative and visual scenarios serve as powerful tools for envisioning the future (Rasmussen, 2008), and can enhance the appeal of scenarios to wider audiences (Lyons et al., 2021). While visualizations are often employed as end results, their use throughout the scenario-building process can stimulate discussion and participation, providing a common basis for communication and improving understanding (Al-Kodmany, 2002; Tobias et al., 2016). The combination of visual materials with verbal communication can also enhance the perceived trustworthiness of the results (Graham Saunders, 2009). Various data elicitation methods, including focus group discussions (Nyumba et al., 2018), storytelling workshops (Carbonell et al., 2017), and visual mapping techniques (Goodier & Soetanto, 2013), are employed to capture diverse perspectives and organize ideas for scenario development. The Nominal Group Technique (NGT) is particularly effective in ensuring that all participants' voices are heard, promoting a balanced and collective vision (Boddy, 2012). This is achieved by structuring the discussion process to minimize dominant voices and encourage equal participation from all members (Boddy, 2012).

Traditionally, narrative and visual elements in participatory processes have been shaped by local artists (Lazurko et al., 2023), through practices such as visual harvesting (Tori et al., 2023), where they capture and represent collective ideas and discussions in real-time (Mahy, 2012). This method, while deeply rooted in cultural and community engagement, can be time-consuming and dependent on the availability and skill of the artists (Mahy, 2012). However, there is now an opportunity to integrate generative AI into this process, allowing for faster production times and more systematic input (Noy & Zhang, 2023). By utilizing AI, visual and narrative outputs can be generated in a fraction of the time, with the ability to incorporate a broader range of data and ensure consistency across different scenarios (Epstein, 2023). This shift not only enhances efficiency but also opens up new possibilities for scaling these techniques across larger and more diverse groups, ensuring that the visual representation of ideas is both comprehensive and accessible (Verheijden & Funk, 2023).

3. Methods

The study aims to develop and test a participatory methodology that combines Cross-Impact Balance (CIB) analysis with creative and qualitative scenario-building techniques using scenario workshops. CIB analysis generates internally consistent raw scenarios, which need to be complemented by other methods to be fully effective (Weimer-Jehle et al., 2020). Therefore, complementary methods can be used alongside CIB (Kemp-Benedict, 2012). To fully realize the potential of CIB analysis, integrating normative narrative scenarios into the methodology not only complements the logical structure provided by CIB but also enriches the process by fostering creativity and enabling the articulation of innovative, value-aligned futures (Gassner & Steinmüller, 2018).

Normative narrative scenarios are vital for fostering creativity and envisioning alternative futures, as they enable stakeholders to imagine and articulate innovative solutions that align with shared values and aspirations (Gassner & Steinmüller, 2018). These scenarios encourage a narrative-driven approach to planning, where storytelling becomes a tool for exploring diverse possibilities and crafting compelling visions of the future (Wiek & Iwaniec, 2014). By integrating creativity and narrative into scenario planning, these approaches help bridge the gap between abstract goals and concrete actions, making complex ideas more relatable and actionable (Kok et al., 2011).

In this study, the foundational CIB methodology was further enriched with several additional techniques, including a Delphi questionnaire, qualitative scenario planning workshops, and generative Text-to-Image visualization. These methods, all previously employed in scenario development literature (Tori et al., 2023; Yildirim, 2023), were selected for their ability to complement the logical structuring provided by CIB. The Delphi questionnaire and CIB facilitated the systematic selection and structuring of scenario-defining factors, while the workshops and generative Text-to-Image visualization enabled the creation of narratives and visuals that enhance stakeholder communication and engagement. This integrated approach is particularly effective for developing participatory scenarios tailored to the complexities of adaptive reuse and the diverse stakeholders involved in shaping it. The proposed methodology consists of eight sequential steps, as illustrated in Fig. 1, with Steps 1, 3,4 and 5 being integral to the original CIB methodology (Weimer-Jehle, 2006).

By combining these methods, the research aims to create a robust and adaptable framework capable of addressing the multifaceted challenges of adaptive reuse projects.

3.1. Step 1: inventory of drivers

The initial step in CIB involves compiling an inventory of drivers, which are the uncertainty factors anticipated to impact the subject matter, in this instance, the circular adaptive reuse of buildings (Weimer-Jehle, 2006). For this purpose, desk research on the factors affecting adaptive reuse was conducted. A comprehensive inventory of drivers from existing literature review(s) can be used as the starting point for driver selection, acknowledging that selecting the right descriptors is crucial in CIB analysis. Missing key factors or using unclear definitions can significantly weaken the analysis (Weimer-Jehle, 2023). By utilizing a broad overview of drivers, the risk of overlooking critical drivers can be somewhat mitigated, although the possibility of missing key drivers remains.

Effective descriptors in the Cross-Impact Balance (CIB) method must be comprehensive, distinct, measurable, actionable, and systematically structured to define the scenario space and support decision-making (van Laar et al., 2024). Studies by Bullen and Love (2011), Vafaie et al. (2023), Vardopoulos (2019), and Mısırlısoy and Günçe (2016) offer key inventories of drivers for developing descriptors for adaptive reuse (Bullen & Love, 2011; Conejos, 2013; Mısırlısoy & Günçe, 2016; Vafaie et al., 2023; Vardopoulos, 2019). Bullen and Love focus on sustainability drivers like economic feasibility and stakeholder alignment (Bullen & Love, 2011), while Conejos highlights adaptability and market demand via the AdaptSTAR model (Conejos, 2013). Vafaie classifies success factors across ten domains (Vafaie et al., 2023), Vardopoulos emphasizes sustainable development drivers like land conservation and cultural heritage (Vardopoulos, 2019), and Mısırlısoy and Günçe present a holistic model integrating heritage, functionality, and environmental dimensions (Mısırlısoy & Günçe, 2016). While these studies provide comprehensive insights into drivers and success factors for adaptive reuse, this research ultimately used the inventory of drivers compiled by van Laar et al. (2024). Van Laar et al. synthesized and structured these insights among others, into a cohesive inventory of decision criteria and objectives, incorporating a broad range of factors (van Laar et al., 2024). In this integrative literature review, important decision criteria, and objectives were substantiated over three phases, using an extended PESTLE-CA framework: Political, Economic, Social, Technological, Legal, Environmental, Cultural, and Architectural (van Laar et al., 2024). These criteria and objectives form a longlist of drivers from which stakeholders can select or prioritize. Clearly stated objectives are essential for a Cross-Impact Balance (CIB) analysis focused on normative scenarios because they define desirable outcomes and guide the selection of relevant descriptors, ensuring alignment with study goals. By translating abstract goals into actionable terms, they ensure that the scenarios generated are not only meaningful but also practically implementable, offering clear pathways toward achieving desired future states.

3.2. Step 2: selection of relevant drivers

To prioritize key drivers for scenario-building, a two-round Delphi questionnaire was conducted with a diverse group of adaptive reuse experts using Qualtrics Software. The Delphi method was chosen because it helps achieve a consensus, reduces the influence of dominant individuals, and improves the reliability of the results through iterative refinement (Schmalz et al., 2021). A two-round Delphi questionnaire involves experts responding to a series of questions in two rounds. In the first round, they provide their opinions independently, and in the second round, they review a summary of the group's responses from the first round, allowing them to revise their answers based on collective feedback (de Villiers et al., 2005). The population of experts was identified through purposive sampling to ensure representation across relevant sectors, including governmental institutions, project development firms, architectural practices, academia, NGOs, and non-profit organizations. Participants were required to have a minimum of five years of experience in adaptive reuse, with demonstrated expertise in policy, design, or implementation. A total of 51 experts were invited to participate in the first round, which consisted of an online survey in English and Dutch. The questionnaire asked participants to rate the importance of pre-identified drivers for future adaptive reuse projects on a scale from 1 (not important at all) to 5 (very important) (For the questionnaire see Appendix A). Participants were also invited to propose additional drivers. In the second round, participants reviewed the summarized group responses from the first round, including average importance ratings and comments, and were given the opportunity to revise their initial responses. Of the 51 experts invited, 18 completed the first round, and 14 completed the second round, achieving a response rate of 35 % and 28 %, respectively. While these rates are relatively low, they are consistent with participation levels commonly reported in Delphi studies. For instance, the Delphi method often emphasizes the quality of expert input over sheer quantity, with guidelines suggesting that panels of 10–30 participants are adequate for achieving reliable consensus, especially when participants are carefully selected for their expertise (Hasson et al., 2000; Hsu & Sandford, 2007).

3.3. Step 3: development of scenario descriptors and variants

Based on the outcomes from the Delphi questionnaire the 15 most important drivers were selected for inclusion in the scenario development process. To balance the trade-off between adequacy and completeness of the scenario analysis a descriptor field between 9 and 15 descriptors is recommended (Weimer-Jehle, 2023). Because CIB analyses are typically performed at a high aggregation level, given the constrained number of descriptors, criteria, and objectives can be combined into one comprehensive descriptor (Fig. 2). The research team developed the written drafts for descriptors and variants and then invited experts to comment on them, following the approach of Pregger et al., (2020). To balance participation and avoid stakeholder fatigue, we decided not to directly involve our stakeholders in this step. For developing the descriptors and their variants, a: "state" descriptor with an ordinal measurement scale was used (Weimer-Jehle, 2023). This approach is chosen because it remains effective even when there is no metric available to measure the distances between the different variants of a descriptor (Weimer-Jehle, 2023). Although the static nature of CIB analysis is often considered a limitation (Weimer-Jehle, 2006,2023), as it hinders application to dynamic systems, it is well-suited for this study due to the normative nature of the scenarios, where static end states are preferred for outlining desired future outcomes. The methodological requirements of the cross-impact balance analysis: *completeness* (the descriptor variants taken together must represent all possible futures of the descriptor), *mutual exclusivity* (no development should be assignable to more than one variant of a descriptor simultaneously), and the *absence of overlap* (the variants of different descriptors don't make a statement about the same topic) were also fulfilled (Weimer-Jehle, 2023).

3.4. Step 4: evaluation of direct effects

Simply mixing descriptor variants without considering their interrelationships risks losing the crucial elements that define a good

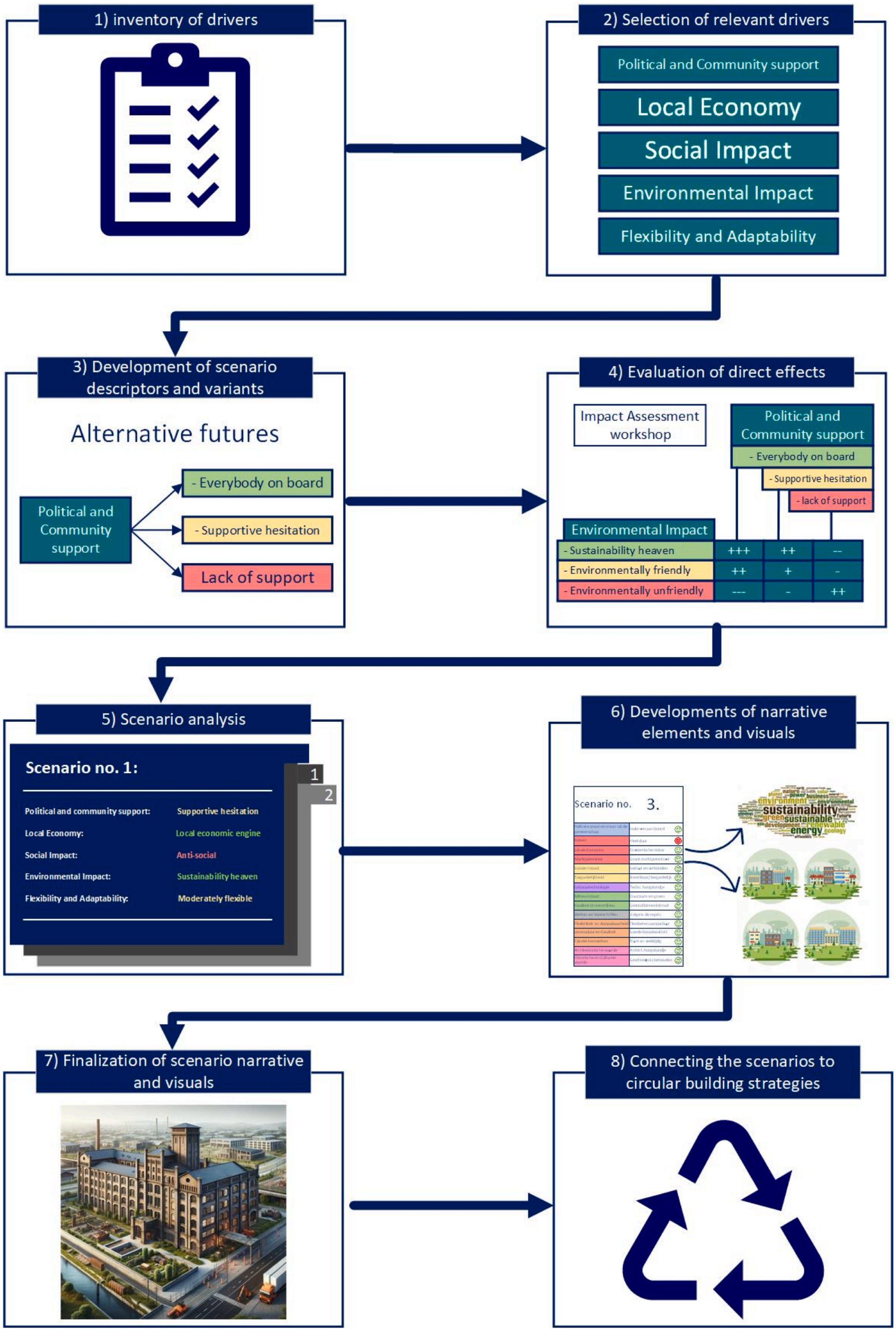

Fig. 1. Overview of the scenario development process.

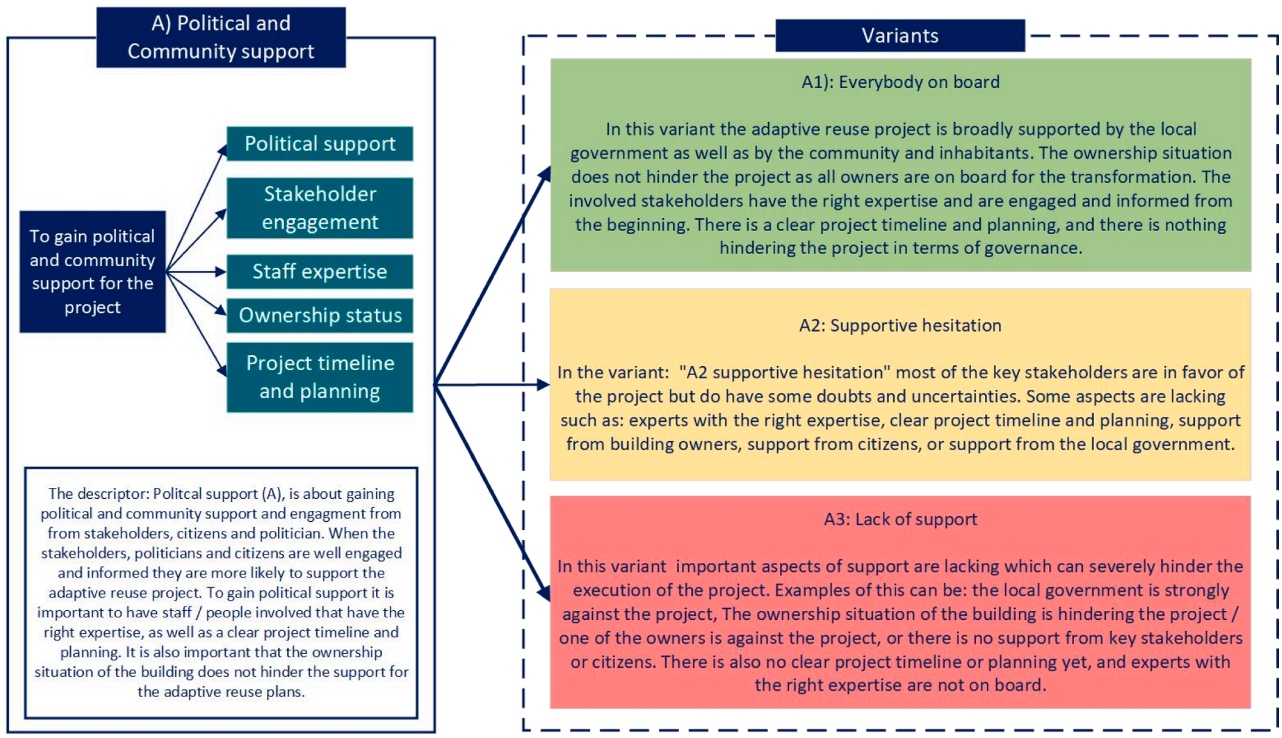

Fig. 2. A detailed overview of the descriptor: "Political and Community Support", with its corresponding variants.

scenario: internal logic and consistency (Weimer-Jehle, 2023). To develop believable scenarios, it is essential to explore these interdependencies. Step 4 involves assessing the direct effects of variants on each other using a cross-impact matrix. For each descriptor, the direct impact of each variant state on the variant states of all other descriptors was evaluated. The scale recommended by Weimer-Jehle (2006) was used (Weimer-Jehle, 2006), which ranges from −3 to +3, allowing a variant state to have a negative, neutral, or positive impact on other variant states (Fig. 3). The matrix was completed during a participatory workshop held on: December 20th 2023, at [anonymized to conceal identifying information], with experts specializing in adaptive reuse, and lasted around 3 h. Experts who had participated in the Delphi questionnaire were also invited to the workshop, with 10 experts ultimately participating, which aligns with the recommended range for number of participants by Weimer Jehle (2023). The expert group comprised professionals from various fields, including architecture, consulting, financial advisory, project management, public administration, building engineering, and project development. Experts were

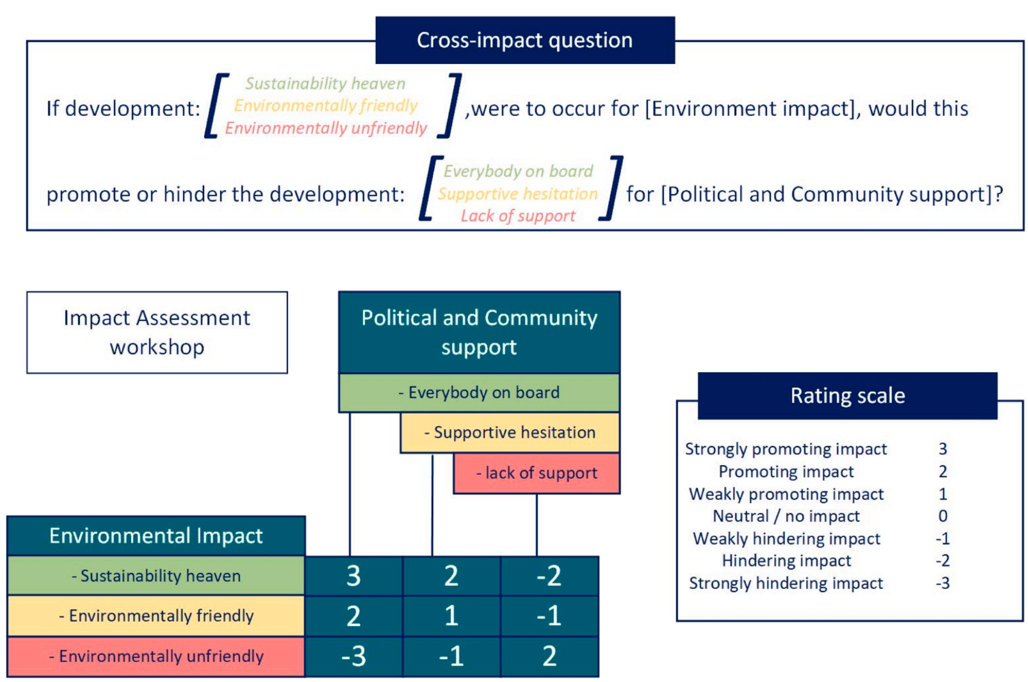

Fig. 3. Example of the identification of relationships in the cross-impact balance analysis.

randomly paired to complete a part of the cross-impact matrix, and their evaluations were then aggregated to reach the final assessment. This approach not only improved the practicality of filling in the cross-impact matrix for larger systems by dividing the workload but also aligns with common practices in CIB methodology, where partitioning the matrix and using comprised evaluations is a standard method for efficiently eliciting data input (Weimer-Jehle, 2023).

3.5. Step 5: scenario analysis

The scenario structure was developed by examining the cross-impact matrix for internally consistent descriptor variant combinations. If the interdependencies among descriptors are not taken into account, any mix of descriptor variants might be seen as a scenario. However, by utilizing the cross-impact matrix, it becomes feasible to evaluate each scenario to determine if it aligns with the interdependencies specified in the matrix. Internal consistency ensures that the scenario logic is free from contradictions (Weimer-Jehle, 2006). The study employed the ScenarioWizard[1] software to conduct the scenario analysis, which uses an algorithm to evaluate the cross-impact matrix for consistency. The algorithm identifies assumption bundles that align with the specified interdependencies among descriptors. The CIB methodology tolerates marginal inconsistencies due to the qualitative nature of the input data. For a CIB matrix with 15 descriptors and 45 variants, an inconsistency value of 2 (impact sum of up to minus 2) was deemed acceptable (Weimer-Jehle, 2023). Using these parameters, 179 consistent scenarios were generated. To refine the results, the selection manager within ScenarioWizard was used to identify 15 scenarios for further analysis in subsequent steps. This selection process applied a scenario diversity score of 6, ensuring that the selected scenarios differed by at least six descriptors (Weimer-Jehle, 2023). This approach maintained a diverse and representative portfolio of scenarios for further refinement. For more details on the CIB algorithm, refer (Weimer-Jehle, 2023).

3.6. Step 6: development of narrative elements and visuals

The raw scenarios generated in Step 5 were further refined in a second participatory workshop, held on January 14th, 2024, at [anonymized to conceal identifying information]. This workshop aimed to transform raw scenarios into narrative scenario elements, incorporating insights from the first workshop. Creative techniques were employed to stimulate imagination and foster innovative thinking, incorporating artistic methods to enrich the narratives (Lederwasch, 2012). The same participants from Workshop 1 were invited to ensure continuity and leverage their familiarity with the process (Gottesdiener, 2003). The workshop structure followed the Nominal Group Technique (NGT) (Boddy, 2012), a method designed to facilitate brainstorming and ensure equal participation among attendees. Utilizing the Nominal Group Technique for brainstorming ensures equal participation, fosters consensus building, and allows for the generation and evaluation of a large number of ideas in a relatively short amount of time (Boddy, 2012). Participants engaged in a structured process to answer ten predefined questions for each draft scenario, focusing on elements such as scenario titles (do Prado Leite et al., 2000), timelines (van Vliet et al., 2012), and visual characteristics (Goodier & Soetanto, 2013) (see Appendix A for the full list of questions). Initially, participants brainstormed on the questions individually, followed by partner discussions to refine their ideas. The session concluded with group discussions to consolidate the outputs.

3.7. Step 7: finalization of scenario narratives and visuals

In the final step of the scenario development process, generative AI tools are employed to visualize adaptive reuse scenarios and create detailed storyline descriptions. These AI tools leverage the comprehensive inputs derived from the CIB building blocks and the insights gathered from previous two workshops. Previous research on the development of scenario narratives and visuals has employed techniques such as visual harvesting (Tori et al., 2023), and engaging local artists (Lazurko et al., 2023). However AI fundamentally alters the creative process, offering speed, consistency, and scalability that traditional methods cannot match (Epstein, 2023; van Laar et al., 2024). generative AI simplifies content creation and allows for customization, enhancing the storytelling experience (Antony & Huang, 2024). The research team developed the scenario descriptions and visualizations using generative AI and then shared them with the workshop participants from step 4 and 6 for reflection and further improvements. For the development of narratives, OpenAI's ChatGPT4, was used. The excel sheets from Step 6 were added to the following prompt: "*Based on the Excel input, write a storyline of an adaptive reuse scenario. Make sure that all descriptor variants are included. Make the storyline between 300 and 400 words.*" In order for the scenario narratives to be consistent across the scenarios, the prompt remained the same, and only the excel input changed.

For the visualisation of the scenarios DALL-E was used. DALL-E is an integrated extension within ChatGPT-4 that specializes in generating images based on textual descriptions provided by users (Marcus et al., 2022). This enabled a quick generation of visuals that were easy to adjust through narrative input. For the generation of images, the scenario storylines were used as input together with the following prompt: "*Create an image of an adaptive reuse scenario, based on the scenario storyline above*". While DALL-E is generally effective at transforming prompts into visual outputs (Marcus et al., 2022), it is advisable to maintain a consistent structure and style across all prompts to ensure uniformity. Once an initial image of the scenario was generated, additional prompts were used to depict different perspectives of the scenario. For the adaptive reuse scenarios, the following prompt was employed to generate images from an interior perspective: "*Create a similar image from the inside point of view looking outside. Keep the same style and scenario*". After generating the storylines and visualizations a comprehensive scenario scorecard was developed for all scenarios (two examples are provided in Figs. 6& 7).

3.8. Step 8: connecting scenarios to circular building adaptability strategies

Although adaptive reuse itself can be considered a circular approach, past approaches have not considered the full potential of circular building approaches (van Laar et al., 2024). To make the adaptive reuse scenarios more circular, strategies can be added to the adaptive reuse scenarios from Step 7. Several frameworks, exist that distinguish circular strategies in adaptive reuse projects (Foster, 2020; Hamida et al., 2024). Foster (2020) proposes a circular economy framework for the adaptive reuse of cultural heritage buildings, emphasizing circular strategies such as: material conservation, sustainable design, and resource-efficient construction to reduce environmental impacts across all project phases (Foster, 2020). Hamida et al. (2024) present a framework with 30 Circular Building Adaptability (CBA) strategies based on case studies and participatory research, categorized into passive (design-focused), active (configuration and user-driven), and operational (process-oriented) strategies (Hamida et al., 2024). To enhance the adaptive reuse scenarios developed in Step 7 with circular building principles, the Circular Building Adaptability (CBA) framework by Hamida et al. (2024) was chosen as it is empirically grounded in participatory research and case studies, offering broader applicability compared to Foster's framework, which is specifically tailored to cultural heritage buildings. A workshop was conducted in collaboration with an expert specializing in circular building adaptability within adaptive reuse. The expert provided insights into the application of CBA strategies for each scenario. During the workshop, strategies were classified into three categories: "always

[1] https://www.cross-impact.org/english/CIB_e_ScW.htm

applicable," "applicable but with barriers," and "not applicable." This structured approach allowed the research team to systematically align each scenario with specific circular strategies. The classifications were based on the descriptors and narratives developed in previous steps. Detailed results from the workshop are included in Appendix C.

4. Results

In this section, we present the results of applying the methodology described in Section 3 to the context of adaptive reuse in The Netherlands.

4.1. Step 1: inventory of drivers

After conducting a comparative analysis of potential inventories of drivers (see Section 3), the framework developed by van Laar et al. (2024) was selected due to its comprehensiveness and suitability for normative scenarios. This framework initially identified 190 criteria and 83 objectives across the PESTLE-CA categories, derived from an extensive review of academic literature (van Laar et al., 2024). After this longlist was reviewed by the research team for potential overlaps, the drivers were consolidated into broader categories. This refinement process resulted in a final set of 71 criteria and 31 objectives, which are detailed in Appendix A. and served as the foundation for the subsequent analysis and scenario development.

4.2. Step 2: selection of relevant drivers

The Delphi questionnaire process yielded significant insights into the prioritization of drivers for adaptive reuse scenarios. In the first round, conducted between November 20th and December 4th, 2023, 18 stakeholders provided responses, representing a range of sectors such as government institutions, project development firms, architects, researchers, NGOs, and non-profit organizations. Stakeholders rated the importance of the pre-identified criteria and objectives from step 1, on a 1-to-5 scale and suggested additional drivers for consideration. This initial round resulted in the addition of five new criteria: "Building typology," "Wind nuisance," "Parking possibilities," "Public safety," "Construction type," "Expandability of the location," and "Possibility to create outdoor façade space (balconies)."

The second round of the Delphi study, held from December 6th to December 20th, 2023, involved 14 participants who had completed the first round. In this phase, participants reviewed summarized feedback from the initial round, including average importance ratings, their own previous responses, and comments from other respondents. Ultimately, the 15 most important objectives, as identified through the Delphi questionnaire, were selected for inclusion in the CIB process, in line with the recommendations of Weimer-Jehle, (2023). These objectives were: *"To gain political and community support for the project", "To reduce cost", "To positively impact the local economy", "To improve the market potential", "To increase social impact", "To improve the technology in the building", "To reduce the environmental impact of the building", "To safeguard the indoor environmental quality", "To comply with local building codes and regulations", "To be flexible and adaptable for future needs", "To improve the physical quality and durability of the building", "To make sure that the physical character of the building allows for adaptive reuse", "To preserve the architectural value of the building", "To preserve to historic and cultural value of the building".*

4.3. Step 3: development of scenario descriptors and variants

The finalized set of scenario descriptors was derived from the 15 most important objectives identified in the Delphi questionnaire. Relevant criteria were integrated to ensure comprehensive representation of each objective. Each descriptor was accompanied by a detailed explanation, aligning with its underlying objective, criteria, and thematic focus. A complete list of all descriptors and their descriptions is available in Appendix B. The scenario descriptors included: *Political and Community Support, Cost, Local Economy, Market Potential, Social Impact, Accessibility, Building Technology, Environmental Impact, Indoor Environmental Quality, Rules and Regulations, Flexibility and Adaptability, Durability and Quality, Physical Characteristics, Architectural Value, and Historic and Cultural Value.* These descriptors served as the foundational elements for the scenario development process, representing key aspects of adaptive reuse projects.

For each descriptor, three ordinal variants were developed: a strong variant (objective fully achieved), a medium variant (objective partially achieved), and a weak variant (objective not achieved). These variants were carefully constructed to meet the methodological requirements of completeness, mutual exclusivity, and absence of overlap (Weimer-Jehle, 2023). Appendix B provides a detailed overview of all descriptors and their corresponding variants. The descriptor "Political and Community Support" exemplifies this approach, with its variants capturing varying degrees of public and political backing for adaptive reuse projects. Fig. 2 illustrates this descriptor and its associated variants, showcasing how each variant aligns with the predefined objectives. This structured approach ensured that the descriptors and variants effectively captured the breadth of possibilities within the adaptive reuse scenarios, providing a robust foundation for subsequent analysis and scenario building.

4.4. Step 4: evaluation of direct effects

The evaluation of the direct effects between variant states produced a comprehensive cross-impact balance matrix that captured the interdependencies among descriptors. The participatory workshop held on December 20th, 2023, brought together 10 experts specializing in adaptive reuse, aligning with the recommended participant range for CIB methodology (Weimer-Jehle, 2023). Following the individual pair assessments, a group discussion facilitated the sharing and validation of evaluations. This collaborative approach ensured that the reasoning behind the assessments was transparent and well-documented. The workshop's outputs were consolidated into the final cross-impact balance matrix (Fig. 4), which serves as the foundation for identifying internally consistent scenario combinations. This matrix reflects the collective expertise and consensus of the participants, providing a robust basis for scenario development that accounts for the critical interdependencies among the descriptor variants.

4.5. Step 5: scenario analysis

The scenario analysis resulted in the generation of 179 consistent scenarios from the cross-impact balance matrix, which included 15 descriptors and 45 variants. These scenarios were evaluated based on their internal consistency, with an acceptable inconsistency threshold of 2, as recommended in the literature (Weimer-Jehle, 2023). The ScenarioWizard software's algorithm verified the interdependencies among descriptors, ensuring that the selected scenarios adhered to the predefined criteria. For practical application, 15 scenarios were selected using the ScenarioWizard software's selection manager. This selection was guided by a scenario diversity score of 6, ensuring that the scenarios differed in at least six descriptors to maintain diversity. These 15 scenarios represent a balanced portfolio, providing a range of plausible and internally consistent outcomes. Fig. 5 illustrates the selected scenarios, which serve as the basis for further refinement and analysis in subsequent steps.

4.6. Step 6: development of narrative elements and visuals

The second participatory workshop successfully refined the 15 draft scenarios into detailed narratives. Using the template provided in Appendix D, participants worked in pairs to address key aspects of each

Fig. 4. The completed cross-impact balance matrix from the scenario development workshop.

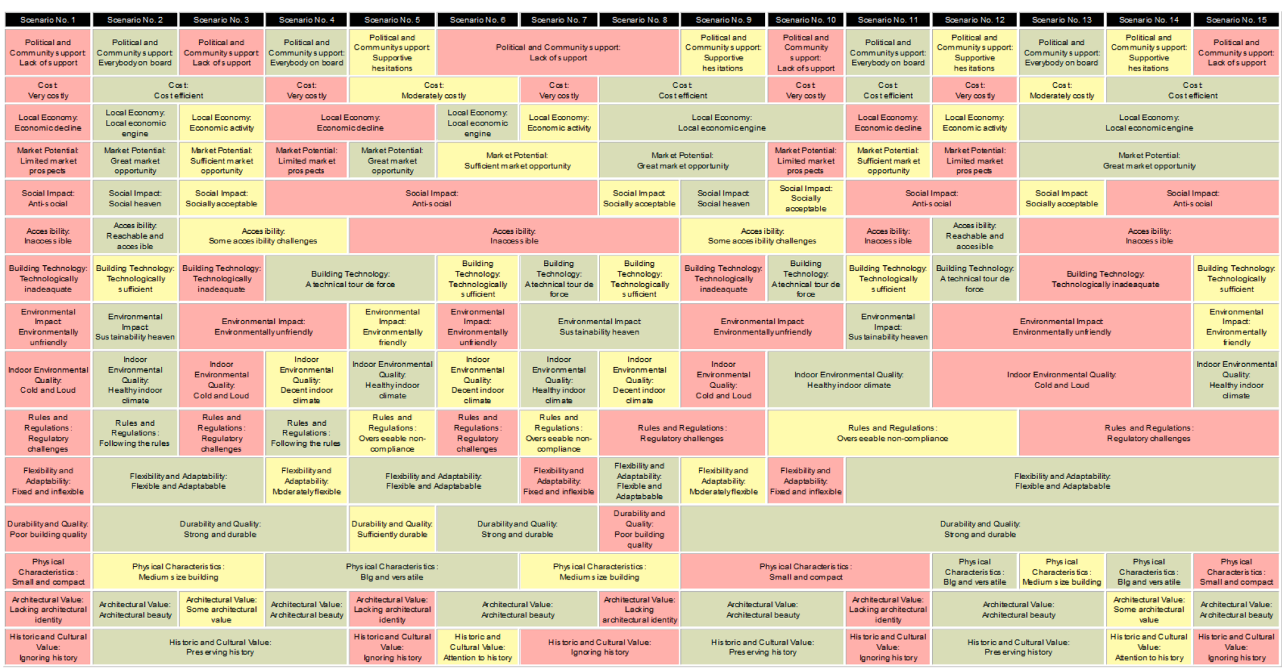

Fig. 5. The scenario tableau for the adaptive reuse scenarios (outcomes from the ScenarioWizard software).

scenario. Responses to the ten questions were recorded, along with detailed explanations of how the scenarios could manifest in real life. Each pair presented their work to the larger group, fostering collaborative refinement of the scenario narratives. The recorded responses and variant descriptions were compiled into an Excel sheet for further analysis (see Appendix B). This structured process yielded comprehensive scenario narratives enriched with creative elements, including scenario titles, visual timelines, and illustrative characteristics. These narratives form the foundation for further scenario exploration and application in the subsequent steps.

4.7. Step 7: finalization of scenario narratives and visuals

The research team successfully developed detailed scenario narratives and visualizations using generative AI tools. ChatGPT-4 was employed to produce consistent storylines for each adaptive reuse scenario, with inputs from the Excel sheets generated in Step 6. The standardized prompt ensured uniformity in narrative style, resulting in storylines that integrated all descriptor variants and ranged between 300 and 400 words. DALL-E was utilized for visualizing the scenarios, generating initial images based on the narratives and refining them iteratively. Interior perspectives of scenarios were created using tailored prompts to maintain visual coherence. The visualizations effectively illustrated the narrative elements, providing stakeholders with a vivid depiction of the scenarios.

The finalized scenario scorecards, combining narrative and visual components, are presented in Figs. 6 and 7. These scorecards serve as comprehensive representations of the scenarios, designed for stakeholder engagement and further discussion. While these outputs represent just one set of possibilities, they demonstrate the scalability and adaptability of generative AI in enhancing the storytelling and visualization processes.

4.8. Step 8: connecting scenarios to circular building adaptability strategies

The adaptive reuse scenarios developed in Step 7 were successfully connected to circular building adaptability strategies using the CBA framework proposed by Hamida et al. (2024). During the workshop with a circular building adaptability expert, strategies were analyzed and categorized for each scenario. The classifications into "always applicable," "applicable but with barriers," and "not applicable" provided a clear framework to understand the potential of circularity within each scenario. Appendix C contains the detailed mapping of strategies to scenarios, offering a practical reference for stakeholders seeking to enhance the circularity of their adaptive reuse projects.

5. Discussion

5.1. Overview of the followed approach

The findings from this research demonstrate that by combining CIB with qualitative scenario-building workshops, it is possible to create comprehensive, internally consistent, and diverse scenarios that effectively capture the complexities of adaptive reuse projects.

One of the key contributions of this research lies in the successful integration of multiple methods, CIB analysis, Delphi questionnaires, participatory workshops, and narrative and visuals created through generative AI, to develop adaptive reuse scenarios. Each method contributed to a different aspect of the scenario development process, from the systematic selection and structuring of scenario-defining factors to the creative elaboration of narrative and visual elements. This mixed-methods approach enabled the generation of scenarios that are both scientifically rigorous and creatively engaging.

5.2. Discussion on the followed approach

The initial driver inventory from a literature review (van Laar et al., 2024), followed by selection via a Delphi questionnaire, effectively contributed to developing general, big-picture scenarios with diverse participant involvement. However, the consensus-driven Delphi method may have limited divergent thinking, potentially overlooking unconventional factors (Tori et al., 2023). Adopting a more flexible approach that didn't rigidly follow Delphi results allowed for a broader range of drivers, but starting with qualitative interviews or open questions could also introduce more locally relevant factors into the scenarios, especially if the process were applied to a specific project.

The use of participatory workshops was highly effective in increasing stakeholder engagement and ensuring that the scenarios were grounded in practical, stakeholder-driven insights (Nygrén, 2019). However, implementing a participatory CIB methodology often requires significant time and resources, which means that careful decisions must be made about when and where to involve stakeholders to maintain overall efficiency (Weimer-Jehle, 2023). In this study, we opted for a centralized, expert-driven approach to develop descriptors and variants. This approach sped up the process but had the downside of potentially

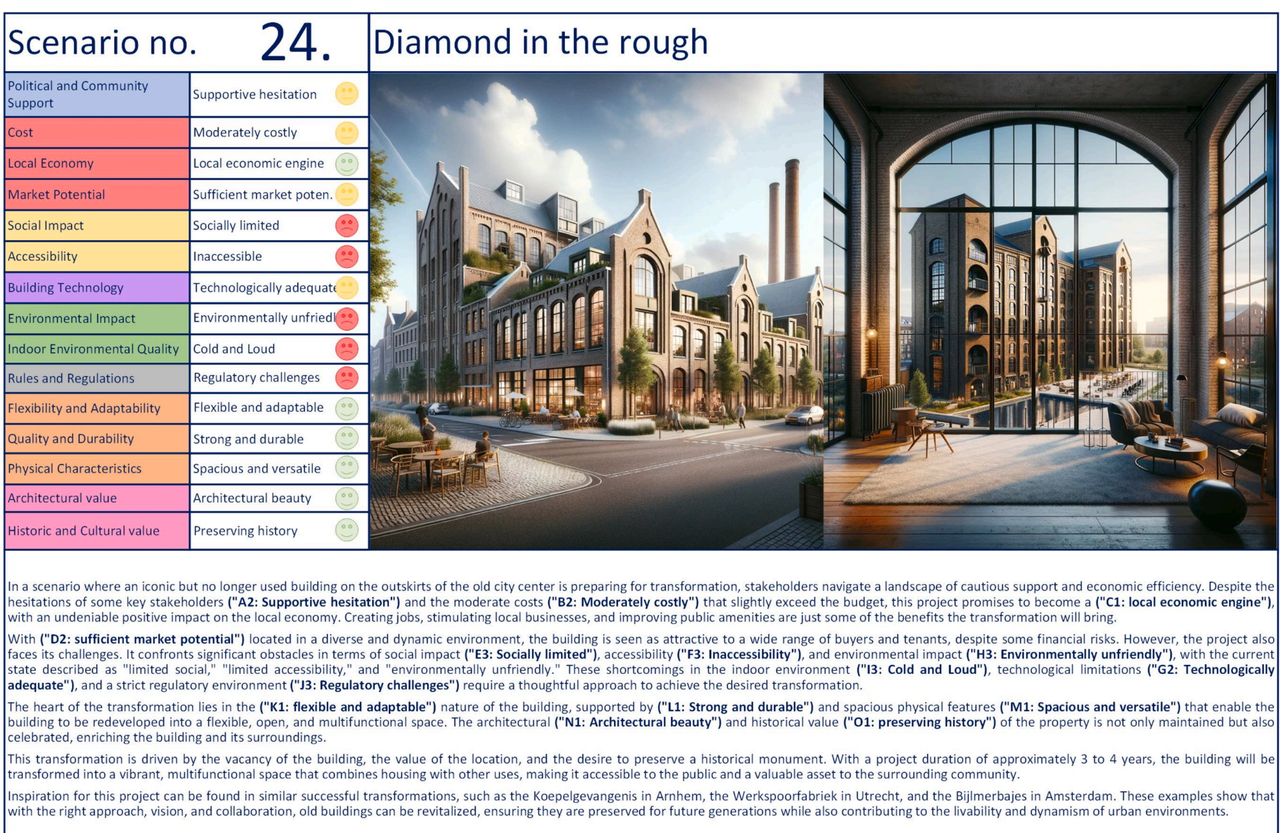

Fig. 6. An excerpt of the adaptive reuse scenario scorecard: "Diamond in the rough".

Fig. 7. An excerpt of the adaptive reuse scenario scorecard: "The Dream".

missing out on diverse stakeholder perspectives. On the other hand, involving a wide range of stakeholders during the development of descriptors and variants could have enriched the scenarios with more localized insights, but it would have also slowed down the process considerably. A phased approach, starting with expert input and followed by stakeholder refinement, proved to be effective in balancing efficiency with inclusivity. This strategy allowed for the rapid development of scenarios while still incorporating valuable stakeholder feedback in later stages. Additionally, separating the participatory data collection from the computational scenario modelling helped avoid lengthy sessions, which can often lead to stakeholder fatigue (Kurniawan et al., 2022).

Integrating CIB methodologies with participatory workshops was beneficial for gathering data in a structured and inclusive way, particularly for general "big picture" scenarios. However, for specific projects, different strategies might be needed to strike the right balance between stakeholder engagement and process efficiency. This could include also involving stakeholders in different phases of the process to ensure both speed and inclusivity.

The integration of generative AI tools, such as OpenAI's GPT-4 and DALL-E, significantly enhanced the consistency and creativity of scenario narratives and visualizations in this study. AI's ability to swiftly process stakeholder input and generate coherent narratives based on structured inputs facilitated the development of detailed scenarios that aligned with the logical structures outlined by the Cross-Impact Balance (CIB) analysis. This efficiency and scalability stand out as key advantages, allowing for the rapid creation of multiple scenario narratives and visualizations, which traditionally would be time-consuming and resource-intensive. The use of AI also proved particularly valuable in participatory settings where time constraints are prevalent, as it enabled the immediate production of visual representations, thereby bridging the gap between abstract concepts and tangible outcomes. This approach made the scenarios more accessible to all participants, enhancing stakeholder engagement and decision-making, consistent with findings by Lyons et al. (2021). In this study, we employed a hybrid approach, where AI-generated visuals and narratives were based on stakeholder inputs and then communicated back for feedback. While this method accelerated the process, refining prompts collaboratively with stakeholders could further enhance the collection of insights that might be missed during the initial workshops.

The incorporation of circular building adaptability (CBA) strategies into the scenarios represents a significant advancement in the field of adaptive reuse. Traditionally, adaptive reuse projects have focused primarily on extending the life of existing buildings, with less emphasis on integrating broader circular economy principles (Ikiz Kaya et al., 2021). By linking scenarios to CBA strategies, the research offers a more holistic approach that considers the full potential of circularity in the built environment. This shift could lead to more sustainable and resilient adaptive reuse projects, capable of combining abstract "big picture" scenarios with tangible circularity strategies. While connecting the big-picture scenarios to the CBA strategies through the help of an expert is effective, its effectiveness would be greatly enhanced by applying it to real-world case studies rather than focusing solely on big-picture scenarios. The development of abstract, generalized scenarios provides valuable insights into the potential of adaptive reuse, but it does not fully capture the specific challenges and opportunities that arise in individual projects.

5.3. Limitations

Despite the comprehensive approach of this study, several limitations should be noted. While the Cross-Impact Balance (CIB) analysis has strengths such as transparency and reduced subjectivity (Schweizer, 2020), it also has inherent limitations. The method is time-consuming, restricts the number of factors that can be considered, and prioritizes consistency as the main criterion for scenario selection (Weimer-Jehle, 2023). This emphasis on consistency may exclude scenarios that, while inconsistent, could have led to valuable discussions and insights. The scenario selection process, managed by the ScenarioWizard software, sought to balance consistency and diversity. However, this reliance on software-driven criteria may have overlooked potentially insightful scenario combinations.

The use of participatory methods, while beneficial for ensuring inclusivity, proved to be resource-intensive and time-consuming. Balancing the need for thorough stakeholder engagement with practical time and resource constraints was challenging. Consequently, certain steps in the scenario development process, such as the selection of descriptors and variants, were centralized and handled by the research team to expedite the process. While this approach was efficient, it may have excluded some stakeholder insights that could have enriched the scenarios.

The incorporation of generative AI tools like OpenAI's GPT-4 and DALL-E enhanced the efficiency and creativity of scenario narratives and visualizations. However, this reliance on AI also introduces limitations. The quality and specificity of the AI-generated outputs depend heavily on the prompts used, and if these are not carefully crafted, the resulting scenarios may not fully align with stakeholder expectations or capture the complexities of real-world situations. Additionally, AI-generated content may lack the nuanced understanding that human-driven creative processes could offer, an area that remains understudied.

Moreover, while generative AI significantly accelerates scenario development and enhances participatory engagement, its environmental impact cannot be overlooked. The IT sector, driven by computationally intensive technologies like AI, currently accounts for nearly 10 % of global energy consumption (Andersen et al., 2021). This raises concerns about the carbon footprint of deploying AI tools extensively, especially in processes aiming to promote sustainability. However, when compared to traditional methods, AI enables digital-first approaches that reduce the need for physical resources during the experimentation phase (Falcke et al., 2024), potentially offsetting some emissions. Additionally, by streamlining decision-making and aligning stakeholder perspectives more efficiently, AI minimizes wasted efforts and redundant iterations (van Laar et al., 2024). Balancing these trade-offs is essential to ensure that the benefits of AI in creating circular, sustainable futures are not undermined by its environmental costs.

Finally, the integration of Circular Building Adaptability (CBA) strategies into adaptive reuse scenarios represents significant progress in incorporating circular economy principles into the built environment. However, this integration remains largely theoretical, based on expert input rather than real-world application. The effectiveness of these strategies in practice is untested, particularly in the context of specific adaptive reuse projects. Moreover, while the study focused on developing general desirable future scenarios for adaptive reuse, these generalized scenarios may not fully address the unique challenges and opportunities of individual projects, potentially limiting their applicability to specific contexts.

5.4. Broader relevance and future research directions

The methodology and findings of this research have broader implications beyond the specific context of adaptive reuse. The integration of CIB analysis with participatory workshops and AI tools could be applied to other areas like urban planning and sustainability, where complex, multi-stakeholder decision-making processes are required. The approach could also be adapted to address different aspects of the circular economy, such as resource management or waste reduction, where scenario planning can help to explore and plan for uncertain futures.

Although the participatory CIB methodology has proven effective in developing general circular adaptive reuse scenarios, further research should explore its application to more localized, project-specific scenarios. By focusing on a specific context, the methodology can better capture nuanced, locally relevant insights, enhancing the realism and applicability of the scenarios. Additionally, integrating CIB strategies with concrete project goals may improve the alignment between scenario development and practical implementation, ensuring that the outcomes are both actionable and directly tied to local needs and conditions.

Despite the integration of participatory workshops into the CIB methodology, there remains potential to further enhance participatory input in scenario development. In our study, stakeholders were involved in nearly all stages of scenario-building, but their role within the CIB framework primarily focused on validating researcher-generated input. A promising area for future research could involve engaging stakeholders in a more bottom-up approach, such as by allowing them to directly use tools like ScenarioWizard and Generative AI software themselves.

Lastly, further research could explore integrating CIB-developed scenarios into a multi-criteria decision-making (MCDM) model. This could address the identified gap in providing a broader overview of options in adaptive reuse decision-making (van Laar et al., 2024). By systematically evaluating scenario outcomes against multiple criteria, such as environmental impact, economic feasibility, and social acceptability, this approach would enhance decision-making robustness. Incorporating CIB scenarios into MCDM models would enable decision-makers to better balance trade-offs and select strategies that align with their objectives, offering a more comprehensive framework for complex adaptive reuse decisions.

6. Conclusion

The primary goal of this research was to develop a participatory methodology that integrates Cross-Impact Balance (CIB) analysis with creative scenario-building techniques, including generative AI and stakeholder workshops. This approach effectively combines the logical structuring strengths of CIB with creative methods that engage stakeholders, resulting in 15 detailed circular adaptive reuse scenarios. These scenarios, supported by narratives and visualizations, provide stakeholders with a comprehensive understanding of potential future pathways for adaptive reuse. The inclusion of Circular Building Adaptability (CBA) strategies within these scenarios marks a significant advancement, aligning adaptive reuse efforts with circular economy principles and offering a more holistic view of sustainable building practices.

The study demonstrates that this mixed-method approach can bridge analytical complexity with visuals, translating a parametrical approach into imaginary foresight. By blending structured CIB analysis with the creativity fostered in participatory workshops and the efficiency of AI-generated content, the research offers a robust framework for enhancing decision-making in adaptive reuse projects. The feasibility of this methodology was clearly established, with effective stakeholder engagement throughout the process. The inclusion of generative AI notably accelerated the scenario development, enabling the rapid creation of 15 detailed and desirable future scenarios that not only explore a range of possible futures but also serve as practical tools for guiding adaptive reuse projects towards more sustainable and resilient outcomes.

One of the most significant outcomes of the study was the development of a cross-impact matrix, which served as the cornerstone of the scenario-building process. Although the creation of this matrix was time-intensive, its adaptability makes it a valuable tool for future research and practice. The matrix can be refined and reused across various adaptive reuse contexts, potentially becoming a central resource for researchers and practitioners. The 15 scenarios produced through this process also provide a solid foundation for ongoing adaptation and learning within the field.

However, the study also identifies some limitations. The generalization of scenarios, while useful for broad planning, may limit their applicability to specific projects with unique challenges and opportunities. The reliance on expert-driven processes and AI-generated content, though efficient, could restrict the diversity and depth of stakeholder input, potentially missing localized or unconventional insights. Additionally, while the integration of CBA strategies is conceptually robust, it remains largely theoretical and requires practical validation in real-world adaptive reuse contexts.

Future research should focus on refining this methodology by applying it to more localized, project-specific scenarios, thereby capturing more contextually relevant insights that enhance the realism and practical applicability of the scenarios. There is also a need to explore methods for increasing stakeholder participation across all phases of the scenario development process, potentially through more bottom-up approaches that enable stakeholders to engage directly with tools like ScenarioWizard and generative AI software.

Furthermore, integrating CIB-developed scenarios into multi-criteria decision-making (MCDM) models could provide a more comprehensive framework for adaptive reuse decisions. This integration would enable systematic evaluation of scenario outcomes against multiple criteria, such as environmental impact, economic feasibility, and social acceptability, thus enhancing the robustness of decision-making and ensuring that adaptive reuse strategies are better aligned with specific project goals and stakeholder needs.

Declaration of generative AI and AI-assisted technologies in the writing process.

Statement: During the preparation of this work the author(s) used ChatGPT-4 in the writing process to improve the readability and language of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

CRediT authorship contribution statement

Brian van Laar: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Angela Greco:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Conceptualization. **Hilde Remøy:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Funding acquisition, Conceptualization. **Vincent Gruis:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Funding acquisition, Conceptualization. **Mohammad B. Hamida:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Brian van Laar reports financial support was provided by European Health and Digital Executive Agency. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scs.2025.106259.

Data availability

Data will be made available on request.

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