TU Delft Department of Management in the Built Environment
BK Bouwkunde

A Framework for Circular Building Adaptability in Adaptive Reuse

A booklet for the framework description and use

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October, 2024

Delft, the Netherlands

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1. Overview of a knowledge-based framework for promoting circular building adaptability in adaptive reuse: The CBA-AR framework

The CBA-AR framework is a knowledge-based tool that brings together three components, namely determinants the circular building adaptability (CBA) (Hamida *et al.,* 2023a), CBA strategies, and the factors that enable or impede those strategies. Hamida *et al.,* (2023a) defined CBA as *"the capacity to contextually and physically alter the built environment and sustain its usefulness, while keeping the building asset in a closed-reversible value chain.".* **Table 1** lists a brief description of the 10 determinants of CBA (Hamida *et al.,* 2023a).

The CBA-AR framework was developed in response of the need to promote circularity in adaptive reuse while coping with the inevitability of this type of building projects by the means of adaptable design. Thus, CBA constitutes the underlying concept of this framework, while adaptive reuse is perceived as an inevitable means to and a practice of interests.

Possible benefits of promoting CBA in adaptive reuse could enable the built environment to withstand future changes, respond to contextual dynamics, eliminate waste generation, embody the regenerative capacity, and create value out of the assets **(Figure 1)**. In an explanatory video, titled "Exploring the Relation Between Circularity and Adaptability in Adaptive Reuse", Mohammad Hamida explains the interconnection between CBA and adaptive reuse.

Table 1: A brief description of the 10 determinants of circular building adaptability

Determinant	Brief description
Configuration flexibility	The capacity to reconfigure the layout of spaces without utilising external resources and producing waste.
Product demountability*	The capacity to dismantle components and products in a building without inflicting damage and producing waste, so that they can be reused in the building or another building
Asset multi-usability	The capacity to offer a multiplicity of the use of building assets, so that maximising the efficiency of their utilisation
Design regularity	The capacity to provide a regular pattern in the spatial layout and composition of the physical assets in the building, so that facilitating the reuse and remanufacturing of the building components and products afterwards
Functional convertibility	The capacity to y to repurpose the function of a building or part of it, so that promoting its longevity while keeping its value
Material reversibility	The capacity to efficiently provide, utilise and reuse the materials in the building within a reversible value chain.
Building maintainability	The capacity to prolong the utility of the building assets and sustain their performance
Resource recovery	The capacity to regenerate the building resources in a manner that reduces the use of new materials and energy consumption
Volume scalability	The capacity to increase and decrease the size of a building and its spaces in a response to the demands of user or organisation, so that alleviating the shortage and redundancy in the spatial use of the building.
Asset refit-ability	The capacity to efficiently provide state-of-the-art building assets and technologies, while avoiding waste generation or over-invested solutions.

Source: Adapted from Hamida *et al.,* (2023b)

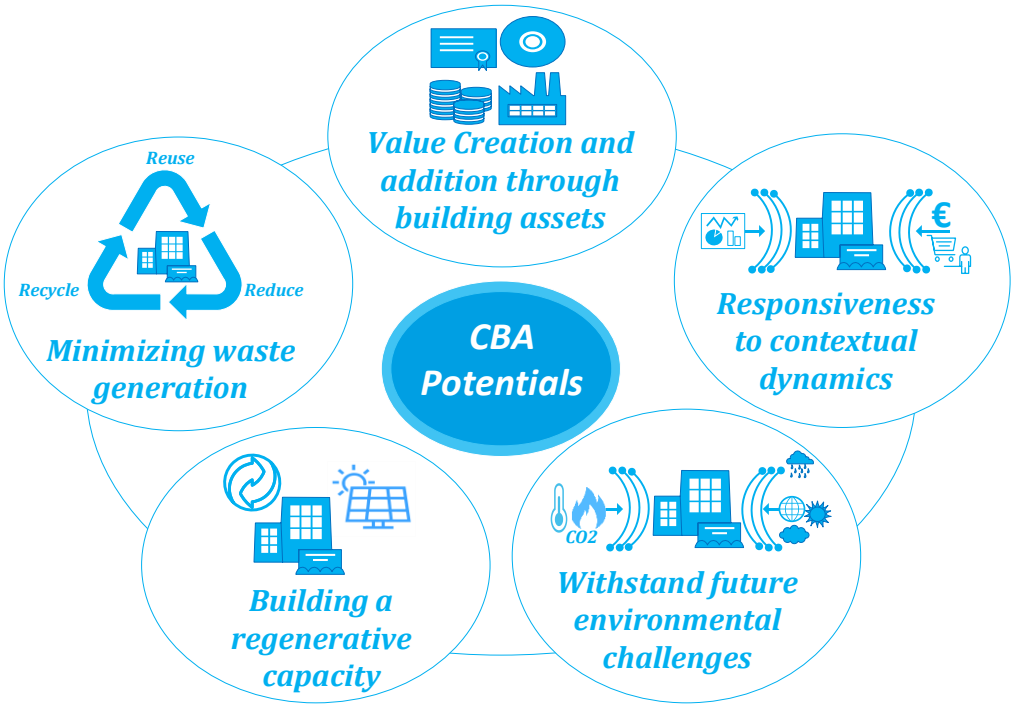
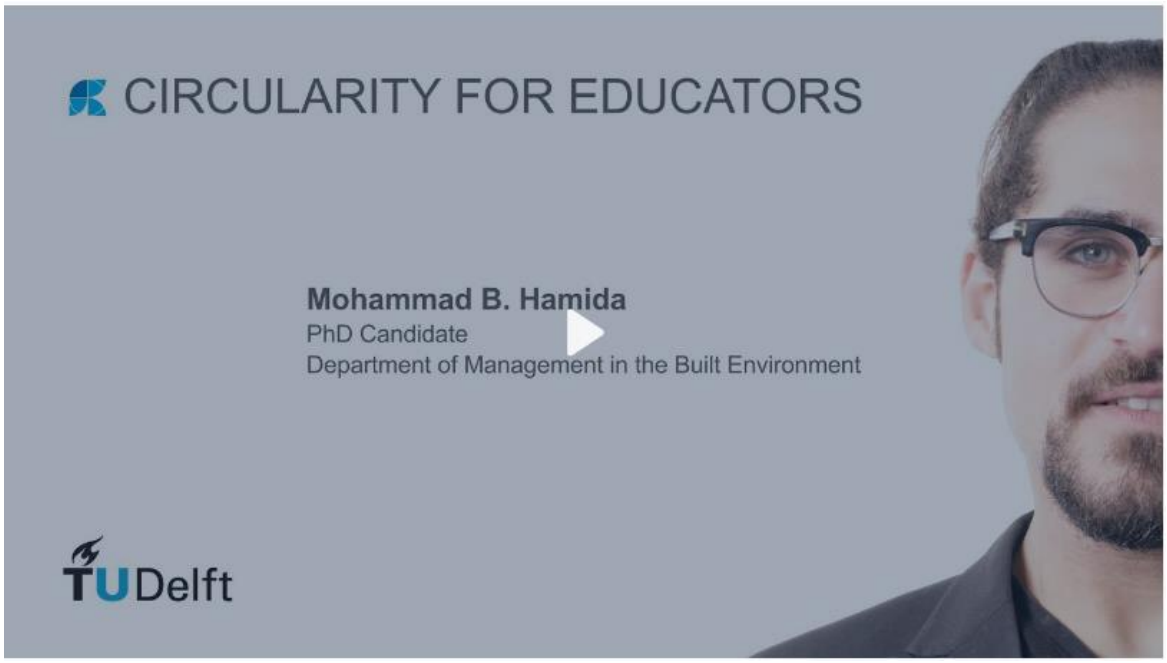


Figure 1: Possible benefits of promoting CBA in adaptive reuse

Source: Hamida *et al.,* (2022)



Exploring the Relation Between Circularity and Adaptability in Adaptive Reuse - Circularity for Educators (tudelft.nl)

The CBA-AR framework is a knowledge-based guiding tool that provides practitioners with the knowledge they need to consider to implement building reuse projects in a circular and adaptable manner. The CBA-AR framework was developed based on the findings of a literature review study (Hamida *et al.,* 2023a), case studies (Hamida *et al.,* 2023b), and co-creation workshops (Hamida *et al.,* 2023c,2024). The framework brings together12 components that are grouped under four blocks, namely quality-related, solution-related, context-related and possibility-related aspects. **Figure 2** illustrates the main blocks of the CBA-AR framework and their components.

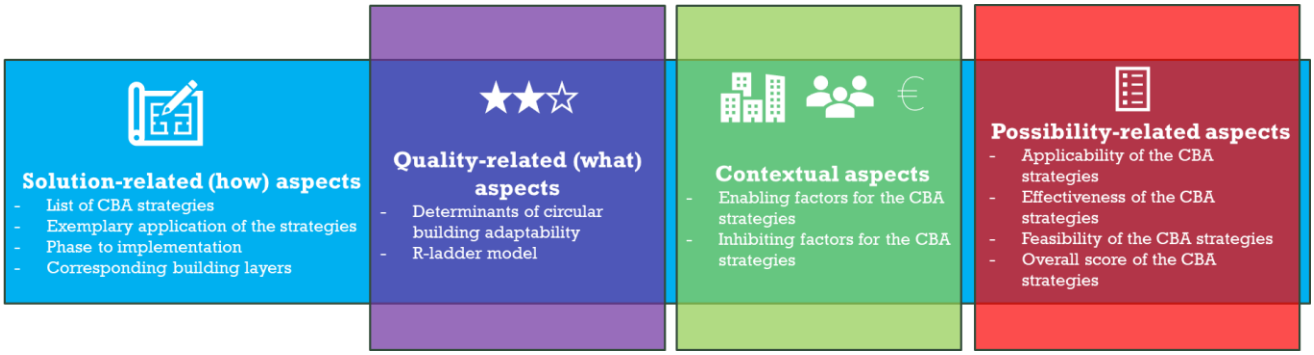


Figure 2: The main blocks of the CBA-AR framework and their components

The quality-related aspects are "what" related, as they provide indicative attributes and characteristics of circularity and adaptability They include the CBA determinants and the R-Ladder model according to Potting *et al*., (2017). The solution-related aspects are "how" related and they mainly relate to the strategies, including examples, phase of implementation, and the corresponding building layers according to the shearing layers model by Brand (1994). The context-related aspects relate to the factors that could facilitate or impede the implementation of the CBA strategies. Finally, the possibility-related aspects relate to the applicability, effectiveness, and feasibility of the CBA strategies. **Figure 3** presents the expanded version of the CBA-AR framework. The use of this framework is threefold, namely as a guiding, assessment, and reporting instrument **(see section 3)**. The CBA determinants represent the qualities that need to be promoted, while the CBA strategies are ways – solutions and actions – for promoting these determinants.

The framework comprises 33 strategies along with 10 enabling and 7 inhibiting factors. The CBA strategies are categorized under three groups, namely as follows Hamida *et al.,* 2023c,2024):

- **Passive strategies** are solutions that can promote CBA through the building design.
- **Active strategies** are solutions that foster CBA through the building configuration and user intervention.
- **Operational strategies** are process-oriented solutions that promote CBA.

Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) (S1. Site, S2. Structure, S3. Skin, S4. Services, S5. Space, S6. Stuff)	Examples	Related Rs from the R-ladder (R0 Refuse, R1 Rethink, R2 Reduce, R3 Re-use, R4 Repair, R5 Refurbish, R6 Remanufacture, R7. Repurpose, R8 Recycle, R9 Recover)	Determinants of Circular Building Adaptability: Adaptability Determinants: Functional Convertibility	Volume Scalability	Asset Refit-Ability	Interrelated Determinants: Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Circularity Determinants: Material Reversibility	Building Maintainability	Resource Recovery	Enabling and Inhibiting Factors: Enabling Factors: The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Inhibiting Factors: Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Evaluation of the Strategies: Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
Passive Strategies																																				
1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2				X	X		X				X	X					X					X					X	4	3	5	4
2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2		X		X	X						X											X	X				X	5	3	4	4
3. Open the Floor Plan	Design	S5	Open office space	R2		X		X							X			X									X				X		4	3	3	3.3
4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1						X					X			X	X							X	X				X		4.5	3	4.5	4
5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	X						X				X	X		X			X						X				X		4.5	3	4	3.8
6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2							X	X			X			X								X							3	4	4.5	3.8
7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	X										X											X	X						3	3	3	3
8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	X	X	X								X				X			X				X	X				X		4	4	3	3.6
9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	X		X								X											X	X				X		4	3	2	3
10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	X										X		X	X		X		X			X	X	X	X		X		5	3	2	3.3
11. Utilization of Secondary (Reused/ Recycled) Materials/ Product	Design	S4, S5. S6	Using second hand furniture	R3 and R8								X		X	X		X	X		X		X		X	X		X	X	X	X	X	X	5	2	1	2.6
12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2								X		X	X		X		X				X	X	X		X			X		4	3.5	2	3.1
13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2								X			X	X	X		X	X			X	X	X		X	X		X		5	3.5	2	3.5
14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-		X									X															X			3	3	4	3.3
15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-				X							X						X												4	4	5	4.3

Legend: Literature-Based Strategy/Factor; Literature- and Practice-Based Strategy/Factor; Practice-Based Strategy/Factor; CO-Creation-Based Strategy/Factor; Co-Creation-Based Linking; Theory-Practice-Based Linking; R0- R2 = Smarter product use and manufacture; R3- R7 = Extend life of product and its parts; R8- R9 = Useful application of materials

Figure 3: The refined and expanded knowledge-based framework for circular and adaptable building transformation

Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) (S1. Site, S2. Structure, S3. Skin, S4. Services, S5. Space, S6. Stuff)	Examples	Related Rs from the R-ladder (R0 Refuse, R1 Rethink, R2 Reduce, R3 Re-use, R4 Repair, R5 Refurbish, R6 Remanufacture, R7. Repurpose, R8 Recycle, R9 Recover)	Determinants of Circular Building Adaptability: Adaptability Determinants: Functional Convertibility	Volume Scalability	Asset Refit-Ability	Interrelated Determinants: Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Circularity Determinants: Material Reversibility	Building Maintainability	Resource Recovery	Enabling and Inhibiting Factors: Enabling Factors: The building Characteristics	Collaboration & Partnership/Industrial Symbiosis	Presence of Motivated/Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Inhibiting Factors: Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Evaluation of the Strategies: Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
Active Strategies																																				
16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1		X		X							X											X	X				X	4	4.5	3	3.8
17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1		X	X	X	X			X			X	X	X									X	X			X	X	5	4.5	4.5	4.6
18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1						X					X				X			X		X					X		X	3	3	5	3.6
19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2										X	X		X				X	X	X	X			X					3	5	5	4.3
20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2										X	X							X					X					4	3	4	3.6
21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1			X	X			X															X	X				X	4	5	5	4.6
22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and R3										X								X				X	X				X	5	3	4	4

Legend: Literature-Based Strategy/Factor; Literature- and Practice-Based Strategy/Factor; Practice-Based Strategy/Factor; CO-Creation-Based Strategy/Factor; Co-Creation-Based Linking (X); Theory-Practice-Based Linking (X); R0- R2 = Smarter product use and manufacture; R3- R7 = Extend life of product and its parts; R8- R9 = Useful application of materials

Figure 3: The refined and expanded knowledge-based framework for circular and adaptable building transformation (continue)

Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) (S1. Site, S2. Structure, S3. Skin, S4. Services, S5. Space, S6. Stuff)	Examples	Related Rs from the R-ladder (R0 Refuse, R1 Rethink, R2 Reduce, R3 Re-use, R4 Repair, R5 Refurbish, R6 Remanufacture, R7. Repurpose, R8 Recycle, R9 Recover)	Determinants of Circular Building Adaptability: Adaptability Determinants: Functional Convertibility	Volume Scalability	Asset Refit-Ability	Interrelated Determinants: Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Circularity Determinants: Material Reversibility	Building Maintainability	Resource Recovery	Enabling and Inhibiting Factors: Enabling Factors: The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Inhibiting Factors: Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Evaluation of the Strategies: Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
Operational Strategies																																					
23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1						X						X			X	X	X	X	X	X				X						5	5	5	5
24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0					X			X	X		X	X	X			X		X			X	X	X	X	X	X	X		5	5	3	4.3
25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1			X			X		X	X			X			X													X	4	2.5	2	2.8
26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and R6								X				X	X		X	X					X	X	X	X	X	X		5	2	2.5	3.2
27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and R8								X				X	X		X	X			X	X	X	X	X	X	X	X		5	4	3	4
28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7								X				X	X		X	X			X	X		X	X	X	X	X	X	5	4	2	3.6
29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and R3						X		X				X	X		X	X	X		X	X		X	X	X	X	X	X	5	2	3	3.3
30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	R4									X						X		X				X		X		X		X		4	4.5	3	3.8
31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	R4 and R5									X				X		X	X						X	X	X		X		X	4.5	4	4	4.2
32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5, S6	Preservation of monumental finishes, doors and windows	R4 and R5								X	X		X		X	X								X	X		X	X		4.5	5	2	3.8
33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	R3				X				X				X	X		X		X								X	X	X	4.5	2	3.5	3.3

Legend: Literature-Based Strategy/Factor; Literature- and Practice-Based Strategy/Factor; Practice-Based Strategy/Factor; CO-Creation-Based Strategy/Factor; Co-Creation-Based Linking; Theory-Practice-Based Linking; R0- R2 = Smarter product use and manufacture; R3- R7 = Extend life of product and its parts; R8- R9 = Useful application of materials

Figure 3: The refined and expanded knowledge-based framework for circular and adaptable building transformation (continue)

The evaluation of the strategies was carried out in collaboration with Experts who scored the strategies in terms of their effectiveness, applicability, and feasibility, using a 5-point rating scheme. The enabling and inhibiting factors are the factors that facilitate or hinder the implementation of the CBA strategies. **Table 2** briefly describes these enabling and inhibiting factors. **Section 2** of this booklet provides an in-depth description of the strategies, including examples, advantages, and disadvantages.

Table 2: A brief description of the enabling and inhibiting factors to the CBA strategies

Enabling factors	
The building characteristics	Availability of flexible size, configuration, and physical and spatial features of the building.
Collaboration and partnership	The presence of collaboration and partnership among the actors and stakeholders of the adaptive reuse project.
Presence of a motivated and capable team	The existence of a shared aim among the engineering team for promoting circularity and adaptability in adaptive reuse.
The economic viability of basic circular strategies	Low cost of reusing old building products and affordability of using second hand building products.
New business models	Adoption of new business models for promoting reversibility of assets in the closed-reversible value chain.
Legislative support	Application of supportive policies and regulations that facilitate the development of adaptable buildings and circular solutions.
Digital technologies	Utilization of technologies enabling for using smart building operation, material passports and renewable energy systems .
Location of the project	The building is located in a multifunctional zone and close to services.
Quality and performance certification	Availability and adoption of a certification of quality and performance of materials and systems
Social acceptance	Acceptance of new circular solutions by society
Inhibiting factors	
Lack of expertise	Lack of knowledgeable and skilled practitioners in CBE.
Technical complexities with building products/material	Poor construction, maladaptive design, and building deterioration.
Economic infeasibility of innovative strategies	High cost of restoring deteriorated building elements, reprocessing discarded materials and repurposing old building products.
The tendency to follow traditional paradigms	The tendency of organizations and practitioners tends to stick to the linear economy paradigm instead of CE.
Lack of data and warranty on materials	Lack of records on the used building materials and their performance.
Legal and legislative restrictions	Rigidity of existing regulations in terms of applying circular solutions
Fragmentation of the building industry	The building industry is piecemeal in terms of processes and products

Source: Adapted from Hamida *et al.,* (2024)

2. Description of the strategies

Following is a brief description of the CBA strategies, their examples, and their advantages and disadvantages:

2.1 Passive CBA strategies

S1. Design standardization

- *Strategy description*: Unitizing the design of building layout and compositions, in terms of their geometry and dimensions, in a repetitive and unitized manner.
- *Example*: Standardizing the layout and types of walls, installations, and openings.
- *Advantages*: Standardizing the dimensions and types of products can be economically feasible, due to the repetitiveness of these physical assets.
- *Disadvantages/challenges*: Design standardization could be restricted in adaptive reuse projects by the original configuration of the building, especially in monumental buildings.

S2. Separation of the building layers

- *Strategy description*: Composing and aligning the physical layers of the building in a separate manner corresponding to their expected service life
- *Example*: Using dry connections in connecting the finishes, installations and other layers instead of wet connections.
- *Advantages*: Separating the building layers can ease their removals and reuse in the long term; thereby saving costs and reducing waste in the long term.
- *Disadvantages/challenges*: Separating the building layers could be hindered by the original composition of materials in adaptive reuse projects of old buildings.

S3. Open the floor plan

- *Strategy description*: Providing an open space within the floor plan that can be divided afterward based on the changing requirements of users.
- *Example*: Providing an open-office space within the floor plan, instead of individual offices, which can be adapted or reconfigured by the tenants.
- *Advantages*: Providing an open office space can provide the users with the flexibility of configuring the open space afterward based on the changing needs.
- *Disadvantages/challenges*: An open office space may lack privacy of speech.

S4. ***Provision of multi-purpose spaces***

- *Strategy description*: Providing a spatial zone or room(s) within the building that can be shared and used by many users
- *Example*: Providing a multi-use space that can be used as a working space and a meeting room.
- *Advantages*: Proving multi-purpose spaces in a building maximizes the space efficiency, as these multi-purpose spaces can be used following a programmed schedule among the users; thereby reducing the need for individual and different spaces.
- *Disadvantages/challenges*: Providing multipurpose spaces requires predicting the space utilization profile as well as a definition of the specific users who can have access to those spaces.

S5. ***Modularization of spatial configuration***

- *Strategy description*: Configuring the spatial layout in a manner consisting of repetitive modules
- *Example*: Configuring the floor plan in a manner that consists of a regular, repetitive, and unitized type and number of spaces.
- *Advantages*: Having a modular configuration of spaces can save costs spent in finishes and installations due to the reactiveness of the layout and size of spaces while facilitating accommodating other functions that require a repetitive layout of spaces (e.g. hotels, apartments, offices, schools, and healthcare buildings).
- *Disadvantages/challenges*: Modularizing the spatial configuration can be impossible in maladaptive or irregular structures, or impeded by the structural elements of the building.

S6. ***Utilization of standardized building products***

- *Strategy description*: Utilizing building products that have standardized size and quality.
- *Example*: Using standardized doors, ceilings and partitions throughout the building.
- *Advantages*: Using standardized building products can be economically feasible when the building accommodates a consistent and symmetrical design while facilitating the reuse of a large number of products in the long term.
- *Disadvantages/challenges*: Using standardized building products can be incompatible with old buildings, due to special and physical limitations associated with the original design of these buildings.

S7. ***Provision of a core for building services***

- *Strategy description*: Providing a core in the building that vertically brings together the building services.
- *Example*: Providing a service core in the building that brings and connects the MEP systems and circulation means together.
- *Advantages*: Having a service core in the building can save the cost of extending services for individual zones, facilitate maintenance and repair (M&R) works, and pave the way for future replacements and alterations based on the changing needs of users.
- *Disadvantages/challenges*: Providing a service core could be impossible in old, irregular, or maladaptive buildings as well as infeasible in small buildings.

S8. ***Design for surplus capacity***

- *Strategy description*: Design the building and its system for extra capacity, exceeding the project requirements, so that future demands can be met.
- *Example*: Oversizing dimensions of spaces, vertically or horizontally, and providing technical systems with a capacity that exceeds the building demand.
- *Advantages*: Having a surplus capacity facilitates meeting the growing demands of users in the long term and accommodating other functions that require more technical performance
- *Disadvantages/challenges*: This strategy can be impossible in existing buildings because of the original design, or impractical when future additions are not possible. Furthermore, this strategy increases expenditures during the redevelopment phase of an existing building.

S9. ***Compartmentalization of design***

- *Strategy description*: Dividing the building into independent compartments (zones), either horizontally or vertically, with their technical systems so that future changes can be easily made on the compartment level.
- *Example*: Dividing the building into independent zones, vertically and/or horizontally, in which each zone would have its supply of services and circulation means.
- *Advantages*: Individual compartments can be repurposed and adapted easily in the long term in response to the changing needs and market dynamics.
- *Disadvantages/challenges*: The applicability of this strategy can be limited in existing buildings due to restrictions associated with the original design. Furthermore, compartmentalization may require providing more services per zone, thereby adding more expenditures to the redevelopment cost.

S10. Design for a mixed-use

- *Strategy description*: Configure the building in a manner that accommodates different functions and can facilitate future repurposing.
- *Example*: Accommodating residential and non-residential uses in the building.
- *Advantages*: From a property investment point of view, this strategy reduces property risks through diversifying sources of income, while reducing possible property vacancy in such kind of mixed-use buildings during market volatility.
- *Disadvantages/challenges*: This strategy might be impossible in monofunctional locations, or restricted by the zoning policies.

S11. Utilization of secondary (reused/recycled) materials/products

- *Strategy description*: The use of second-hand products or secondary materials in the new design
- *Example*: Using second-hand furniture items, such as second-hand office fitouts, and installations such as noise insulations.
- *Advantages*: The cost of using second-hand building products can be cheaper than the cost of using new products.
- *Disadvantages/challenges*: The performance of these products may not be as high as new products, also the compatibility and adequacy of these products can be limited against the requirements of the new design. Therefore, the alignment between using second-hand and new products is necessary.

S12. Utilization of biobased materials

- *Strategy description*: The use of components and products that are made of biological materials.
- *Example*: Using biobased paint, insulations and components that are made out of biological materials (e.g. timber).
- *Advantages*: These products tend to have lower embodied energy.
- *Disadvantages/challenges*: Some of these products may not satisfy the applicable fire safety requirements.

S13. Utilization of circular (reusable/recyclable) materials/products

- *Strategy description*: Use of building products and components that are made of reusable and or recyclable materials
- *Example*: Using furniture items and components that are made of wood (a biobased material), recyclable materials (e.g. steel), and reusable parts (e.g. wet and standardized connections).
- *Advantages*: These parts of these types of products can add value in the long term, as they can be sold out to reuse and recycling agencies while avoiding waste generation.
- *Disadvantages/challenges*: The reusability and recyclability of specific parts of these products may not be determinable or entirely possible.

S14. Alignment of the interconnection between the floor plans

- *Strategy description*: Coordinating the connection between the floor plans in terms of services and circulations.
- *Example*: Locating the plumbing services, shafts, and elevators together in the same location on each floor.
- *Advantages*: Future space utilization and configuration rezoning can be further facilitated at the floor level by aligning the interconnection between the floor plans.
- *Disadvantages/challenges*: Fire safety restrictions, other municipal requirements, and physical constraints can limit aligning the interconnection between the floor plans.

S15. Alignment of the building design with the real estate strategy

- *Strategy description*: Alignment between the building design and the organizational business strategy.
- *Example*: Providing different functions in the building as a means to diversify sources of organizational income.
- *Advantages*: The redevelopment of the adaptive reuse can be in an alignment of other organization- and business-related considerations; thereby prolonging the utility of the adapted building.
- *Disadvantages/challenges*: Implementing this strategy can be limited when the building is being redeveloped exclusively from a developer perspective.

2.2 Active CBA strategies

S16. Utilization of adjustable building components/products to users

- *Strategy description*: use of building products that are versatile and can fit the needs of individual users
- *Example*: Using flexible fit-outs such as adjustable chairs, adjustable desks and folding walls.
- *Advantages*: Adjustable items are user-centred assets, which can contribute to satisfying the preferences of individual users on a daily basis.
- *Disadvantages/challenges*: Some of the adjustable building products could be useless or overinvestment, such as folding walls; therefore providing this type of assets requires an understanding of the specific use pattern of the building spaces.

S17. Utilization of dismountable building components

- *Strategy description*: Using building components that can be easily dismantled.
- *Example*: Providing demountable wall partitions and plug-and-play (PnP) installations and fit-outs that can be easily dismantled and reused in other locations.
- *Advantages*: Using demountable building products can facilitate accommodating future changes, as per the user/owner requirements, while facilitating the reuse of these products in the future; thereby reducing waste generation.
- *Disadvantages/challenges*: The reusability of the demountable products in other projects afterward is not always possible or guaranteed.

S18. Provision of shareable spaces

- *Strategy description*: Providing spaces or rooms within the building that can be used by different users of the building
- *Example*: Providing shareable lounges, toilets, kitchens, and meeting rooms that can be used by different users/tenants of the building.
- *Advantages*: Increasing the efficiency of space utilization and reducing the need for more spaces.
- *Disadvantages/challenges*: This strategy might not always be accepted or preferable by all individuals or organizations; therefore understanding the profile of the end user is necessary.

S19. ***Utilization of renewable energy technologies***

- *Strategy description*: Using renewable resource-based systems to generate building electricity
- *Example*: PV panels, PVT panels, and geothermal pumps.
- *Advantages*: Saving the costs spent on the operational energy, while contributing to reducing using of non-renewable energy sources.
- *Disadvantages/challenges*: These systems could require high investment costs, while their effectiveness could be influenced by the weather conditions as well as physical constraints related to the building and its neighbouring buildings.

S20. ***Enabling the use of natural lighting/ventilation***

- *Strategy description*: Facilitating using natural lighting and ventilation instead of artificial lighting and ventilation systems.
- *Example*: Providing openable and accessible windows in the interior spaces to provide the user with the means of having natural lighting and ventilation during the day time.
- *Advantages*: This strategy contributes to resource renewability, as using natural lighting/ventilation is a way of using resources in a manner that reduces the need to consume non-renewable resources. In addition, natural lighting and ventilation contribute to increasing user stratification with the thermal and visual comfort-related indicators, respectively.
- *Disadvantages/challenges*: Facilitating using natural lighting and ventilation could be limited and hindered by the original design of the building.

S21. ***Utilization of flexible and integrated building installations***

- *Strategy description*: Using flexible building installations that bring together different systems.
- *Example*: Using plug-and-play office cells that include noise insulation and lights. Another example is using plug-and-play (PnP) wall partitions that integrate other services into the wall composition.
- *Advantages*: Providing this type of installation can contribute to coping with the fragmentation between different building systems while facilitating the adaptability of building spaces to the users. Furthermore, the reusability of this type of product is high, as these products may include different parts that can be reused or recycled at the end of the service life of such kind of products.
- *Disadvantages/challenges*: This type of installation may require a higher investment cost, while the adaptability of this type of product is not always needed by the user.

S22. Utilization of water recovery system

- *Strategy description*: Using a system that can treat and circulate the water within the building.
- *Example*: Using a system the can treat and circulate the used water for other purposes in the building.
- *Advantages*: Contributing to promoting circularity in the consumption of water as a resource.
- *Disadvantages/challenges*: This strategy can be economically and technically ineffective.

2.3 Operational CBA strategies

S23. Provision of shareable facilities

- *Strategy description*: Provision of facilities, such as products, that can be used by different users.
- *Example*: Providing shareable charging stations, pantries, and office machines.
- *Advantages*: This strategy can maximize the efficiency of using existing assets by the means of maximizing the number of users of a particular asset; thereby reducing the need for providing more assets.
- *Disadvantages/challenges*: The applicability of this strategy is limited when there are different types of users/tenants in the building.

S24. Application of (or update of) material passports

- *Strategy description*: Documenting the materials used in the building and their specifications.
- *Example*: Register the newly added products and information about their properties and providers.
- *Advantages*: Having documentation of the used building products and materials in the building eases the reuse or selling of these assets afterward.
- *Disadvantages/challenges*: Applying material passports could be expensive and difficult in old buildings owing to the lack of records of the available materials.

S25. ***Procurement of the service of building products***

- *Strategy description*: Purchasing building products in a form of service instead of owning the products
- *Example*: Leasing elevators, office fit-outs, and lights.
- *Advantages*: There is an economic advantage of providing building products as a service, namely saving the costs of unexpected repairs. Obsolescence-wise, providing building products as a service facilitates replacing these products with new ones or returning them to the provider; thereby avoiding waste generation.
- *Disadvantages/challenges*: Providers of this type of product are limited.

S26. ***Selective dismantling***

- *Strategy description*: The process of removing building components and products part by part to avoid their damage and facilitate their reuse
- *Example*: Removing old building partitions, ceiling tiles, and lighting fixtures systematically by demounting them part by part without inflicting damage.
- *Advantages*: Selective dismantling increases the opportunity to reuse or sell the demounted products while reducing the need for implementing repair of damages caused by demolishing old building parts.
- *Disadvantages/challenges*: This strategy can be difficult when removing building products that are attached to monumental elements by wet connections.

S27. ***Send back discarded material for reuse/recycling***

- *Strategy description*: Sending back discarded materials and products to recycling or reuse firms; thereby avoiding waste development.
- *Example*: Sending back old ceiling tiles, plumbing fixtures, lighting boxes, doors, and wall panels to reuse firms.
- *Advantages*: Sending back old building materials for reuse and recycling may constitute an opportunity to generate an economic income.
- *Disadvantages/challenges*: Old building products could deteriorate in old buildings; therefore, providers of second-hand products might be unwilling to purchase this type of product.

S28. ***Repurpose old building materials/products***

- *Strategy description*: Reusing existing building materials or products in a manner that differs from the original purpose for which these products and materials were made
- *Example*: Reusing old products and materials as decoration elements.
- *Advantages*: Avoiding waste generation, and possibly preserving some products that constitute monumental elements in heritage buildings.
- *Disadvantages/challenges*: Repurposing old building materials and products might be expensive, possibly accounting for the same cost of using new materials and products.

S29. ***Products exchange***

- *Strategy description*: Exchanging extra or surplus building products with another second-hand or new products, instead of sending those products to waste
- *Example*: Exchanging old building products with other second-hand/new building products. For example, exchanging old products and materials with other second-hand ones through providers of second-hand building materials.
- *Advantages*: Product exchange may constitute an opportunity to save costs spent in purchasing new products while avoiding waste development.
- *Disadvantages/challenges*: Old products could be physically deteriorated in old buildings; therefore, their exchange might be impossible. Furthermore, the alignment between the exchanged products might be a complex process due to differences of materials and lack of information.

S30 ***Implementation of proactive/predictive maintenance***

- *Strategy description*: Implementing maintenance on the building on a regular basis to prevent any form of building collapse or deterioration.
- *Example*: Adoption and implementation of periodic maintenance of all systems and components in the project.
- *Advantages*: Prolong the longevity and promote the reusability of existing systems and building components.
- *Disadvantages/challenges*: The maintenance of old buildings might be an expensive and complex process.

S31. ***Repair of old building components/systems***

- *Strategy description*: Exchanging extra or surplus building products with other second-hand or new products
- *Example*: Repairing structural, construction, services, and other old building components systems, such as old wall panels, doors, and storing cabinets.
- *Advantages*: Repairing existing systems is a means to prolong the longevity of the physical assets, thereby reducing the need for material resources. It might be cost-effective for expensive systems – such as radiators.
- *Disadvantages/challenges*: Repair of old building systems might be expensive and infeasible for deteriorated assets; therefore, a condition assessment of these assets needs to be conducted.

S32. ***Preservation of monumental/old parts***

- *Strategy description*: Preserving existing monumental components and products used in the building, both externally and internally.
- *Example*: Retaining finishes, components, and products that constitute monumental parts in the building, such as classical windows, doors, and finishes.
- *Advantages*: Preserving monumental parts as a means for heritage conservation. It can be a means for acquiring municipal incentives.
- *Disadvantages/challenges*: Preserving monumental building parts might be incompatible with the characteristics and profile of the new use of the building.

S33. ***Utilization of rented-second-hand products from CE marketplaces***

- *Strategy description*: Leasing second-hand building products instead of buying them
- *Example*: Renting second-hand office fit-outs.
- *Advantages*: Low renting cost.
- *Disadvantages/challenges*: Limited number of providers of this type of product. The quality of the second-hand products might be low.

3. A guide for using the CBA-AR framework as a guiding, assessment, and reporting tool

Initially, a 4-stepwise approach is proposed to use the CBA-AR framework as a guiding, assessment, and reporting instrument. The tool can be used in different phases of the projects, as an indicative and informative instrument. **Figure 4** presents an overview of the steps of using the CBA-AR framework as a guiding, assessment, and reporting instrument. To carry out this process, the presented worksheet in **Figure 5** can be used

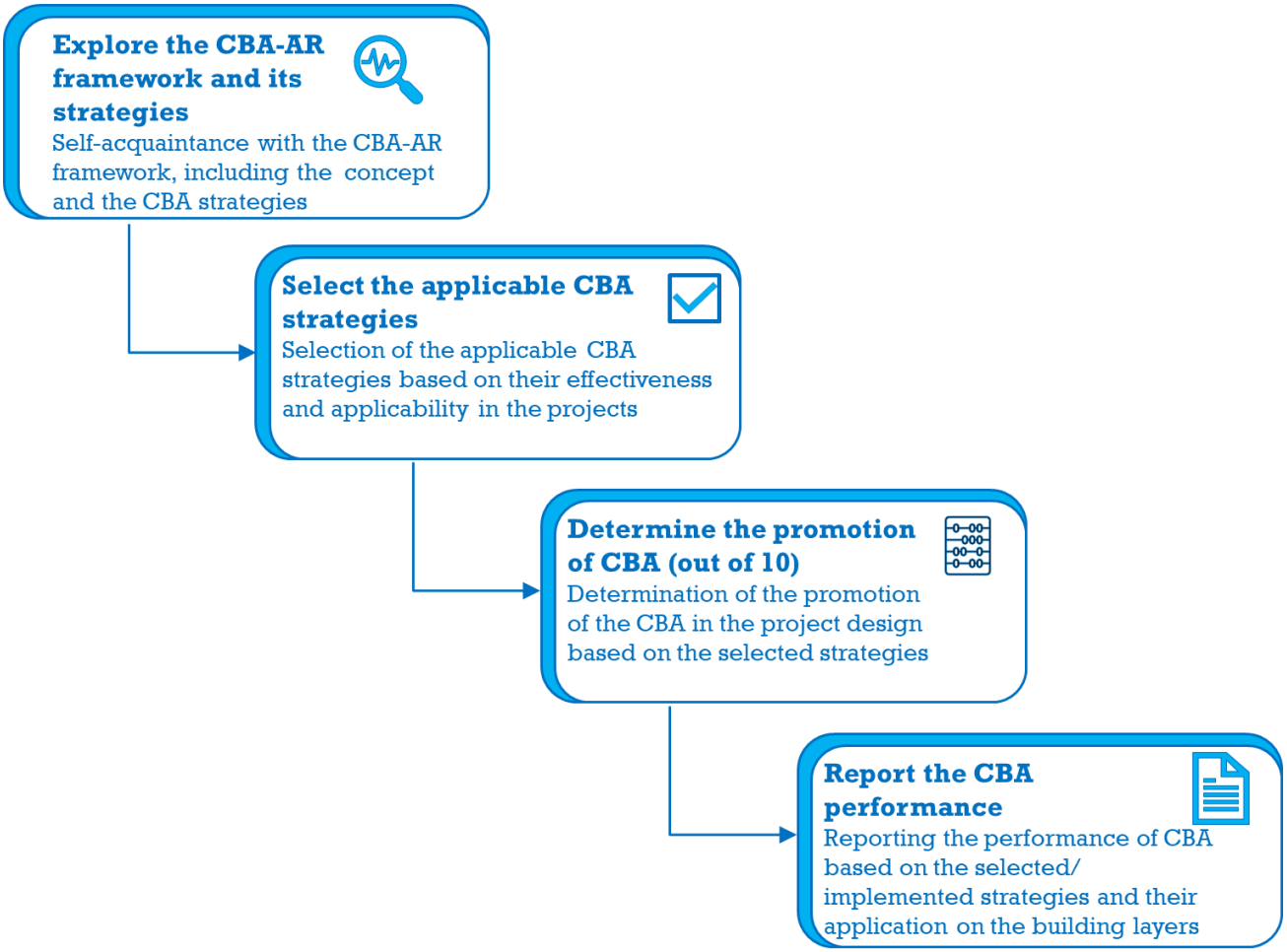


Figure 4: A 4-stepwise approach for using the CBA-AR framework as a guiding, assessment, and reporting instrument

Strategies for Circular Building Adaptability in Adaptive Reuse		Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability										YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
						Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
						Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery					
Passive Strategies	1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2				X	X		X								
	2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2		X		X	X										
	3. Open the Floor Plan	Design	S5	Open office space	R2		X		X											
	4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1						X									
	5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	X						X								
	6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2							X	X							
	7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	X														
	8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	X	X	X												
	9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	X		X												
	10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	X														
	11. Utilization of Secondary (Reused/Recycled) Materials/Products	Design	S4, S5. S6	Using second hand furniture	R3 and R8								X		X					
	12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2								X		X					
	13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2								X							
	14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-		X													
	15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-				X											

Legend: R0- R2 = Smarter product use and manufacture | R3- R7 = Extend life of product and its parts | R8- R9 = Useful application of materials

Figure 5: A worksheet for exploring, determining, assessing, and reporting the promotion of CBA in adaptive reuse design

Note: Yellow fields must be filled out by the user, if applicable

Strategies for Circular Building Adaptability in Adaptive Reuse		Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability											S3. Skin	S4. Services	S5. Space	S6. Stuff
						Adaptability Determinants			Interrelated Determinants				Circularity Determinants								
						Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery					
Active Strategies	16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1		X		X											
	17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1		X	X	X	X			X							
	18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1						X									
	19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2										X					
	20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2										X					
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1			X	X			X								
	22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and R3										X					

Legend: R0- R2 = Smarter product use and manufacture | R3- R7 = Extend life of product and its parts | R8- R9 = Useful application of materials

Figure 5: A worksheet for exploring, determining, assessing, and reporting the promotion of CBA in adaptive reuse design (continue)

Note: Yellow fields must be filled out by the user, if applicable

Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability: Adaptability Determinants: Functional Convertibility	Adaptability Determinants: Volume Scalability	Adaptability Determinants: Asset Refit-Ability	Interrelated Determinants: Configuration Flexibility	Interrelated Determinants: Product Demountability	Interrelated Determinants: Asset Multi-Usability	Interrelated Determinants: Design Regularity	Circularity Determinants: Material Reversibility	Circularity Determinants: Building Maintainability	Circularity Determinants: Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
Operational Strategies																					
23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1						X											
24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0					X			X	X								
25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1			X			X		X	X								
26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and R6								X									
27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and R8								X									
28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7								X									
29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and R3						X		X									
30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	R4									X								
31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	R4 and R5									X								
32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5,S6	Preservation of monumental finishes, doors and windows	R4 and R5								X	X								
33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	R3				X				X									

Legend: R0- R2 = Smarter product use and manufacture | R3- R7 = Extend life of product and its parts | R8- R9 = Useful application of materials

Figure 5: A worksheet for exploring, determining, assessing, and reporting the promotion of CBA in adaptive reuse design (continue)

Note: Yellow fields must be filled out by the user, if applicable

The following video briefly explains these four steps and the shown hypothetical example in **Figure 6**.

3.1 Step 1 – Explore the CBA-AR framework and its strategies

In this phase, an architect, developer, designer, or student will acquaint herself/himself with the CBA-AR framework, starting from the CBA concept and the detailed description of the strategies. Thus, **section 1** and **section 2** need to be carefully read, respectively, by the user of the framework. By going through **sections 1** and **2**, the user will be able to initially know the possible strategies for the project under development.

3.2 Step 2 – Select the applicable CBA strategies

In this phase, the user will select the applicable strategies; therefore filling out the worksheet (Figure 5). The user needs to choose and indicate the specific solutions that will be applied in line with the shearing layer model of Brand (1994), CBA determinants of Hamida *et al.* (2023a), and the R-ladder model (Potting *et al.*, 2017). The 16th column (Yes/No) included in **Figure 5** needs to be filled out first in this step, in addition to the shearing layers scheme (columns 17-20) based on the put-forward solutions.

3.3 Step 3 – Determine the promotion of CBA

Based on the selected strategies, the user will determine in this phase how many of the 10 CBA determinants have been promoted in the adaptive reuse design and also indicate in which building layers these determinants have also been promoted. In addition, the user can indicate which circularity level has been fulfilled based on the relation of the strategies to the R-Ladder model, as a proxy for the actual measurements of circularity. **Figure 6** and **Figure 7** provide an example of using the CBA-AR worksheet as an assessment and reporting tool, respectively.

3.4 Step 4 – Report the CBA performance

In this phase, the user will compile a report of the CBA performance according to what is mentioned in **section 3.3**, using the filled-in CBA-AR worksheet **(Figure 6)** as a reference template.

Example

Suppose that a developer who owns a vacant office building has worked with an architect to convert the vacant office into a mixed-use building by incorporating residential apartments, shops, and co-working spaces into the building configuration. After exploring the CBA strategies included in the CBA-AR framework, they selected 21 strategies to implement in the project, and therefore, they incorporated these strategies into the plan and definitive design of the project. Following are the selected strategies along with their practical solutions (examples):

- **Design standardization** (of doors and windows).
- **Separation of the building layers** (by using dry connections in all services, installations, and fit-outs).
- **Providing an open space** as a co-working area on the first floor.
- **Providing a multi-purpose hall** on the ground floor.
- **Modularizing the configuration of spaces** and layout of MEPs.
- **Utilization of standardized building products** (MEP fixtures, wall panels, and office fit-outs)
- **Providing two cores for building services** (elevators and MEPs).
- **Design for surplus capacity** by oversizing the heating system and providing a rooftop extension
- **Compartmentalization of design** by dividing the floor plan horizontally into independent zones with their own MEP supply and other services.
- **Design for mixed-use** by using high-quality façade materials, oversizing the MEPs and providing residential and commercial uses within the building function.
- **Utilization of biobased (biological) materials** by using bio-based wall panels and desks.
- **Utilization of circular materials/products** by using reusable glass panels and frames.
- **Alignment of the interconnection between the floor plans** by coordinating and connecting all floors by a stair and elevator.
- **Alignment of the building design with the real estate strategy** by including different functions in the buildings as a means to diversify organizational income.
- **Utilization of dismountable building components** by using demountable lighting fixtures, demountable ceilings, demountable partitions, and PnP cubicles.
- **Provision of shareable spaces** by providing a shareable lounge and seating area in the building.
- **Utilization of renewable energy technologies** by using façade and rooftop PVs and geothermal heat pumps.
- **Procurement of the service of building products** by leasing the new elevators.
- **Selective dismantling** by selectively dismantling old curtain walls.
- **Sending back the** selectively dismantled curtain walls for **reuse**.
- **Implementation of proactive maintenance** of the MEP systems by adopting a maintenance program for all MEPs

In this example, the developer and architect would fill out the worksheet as shown in **Figure 7**, and thereby, they determined the promotion of CBA, considering the corresponding building layers and R-measures from the R-ladder model. The 10 determinists of CBA have been promoted through four layers of the shearing layer model. Reflecting on the R-ladder model, the architect and developer have been able to achieve a high level of circularity, as 16 out of the 21 CBA strategies are exclusively related to the so-called smarter product use and manufacture

Figure 6: A hypothetical exemplary case of using the CBA-AR framework as a guiding, assessment, and reporting tool

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability: Adaptability Determinants – Functional Convertibility	Volume Scalability	Asset Refit-Ability	Interrelated Determinants – Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Circularity Determinants – Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
Passive Strategies	1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2				X	X		X				✓			Doors and windows	
	2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2		X		X	X						✓		Dry connections	Dry connections	Dry connections
	3. Open the Floor Plan	Design	S5	Open office space	R2		X		X							✓			Open co-working space on the FF	
	4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1						X					✓			Multi-purpose hall	
	5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	X						X				✓		The layout of MEP systems is regular	Modular configuration of offices	
	6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2							X	X			✓		Standardized MEP fixtures	Standardized wall panels	Standardized office fit-outs
	7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	X										✓			Two cores accommodating lifts and MEPs	
	8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	X	X	X								✓		Oversizing the heating system	Rooftop extension	
	9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	X		X								✓		Each floor has its own MEP supply	The floor are independent from each other	
	10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	X										✓	High quality façade materials	Oversizing the MEPs	Residential and commercial spaces	
	11. Utilization of Secondary (Reused/Recycled) Materials/Products	Design	S4, S5. S6	Using second hand furniture	R3 and R8								X		X					
	12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2								X		X	✓			Bio-based panels	Bio-based tables
	13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2								X			✓			Reusable glass panels and frames	
	14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-		X									✓			All floors are connected by a stair and elevator	
	15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-				X							✓			Different functions are incorporated to diversify income	

Legend R0- R2 = Smarter product use and manufacture | R3- R7 = Extend life of product and its parts | R8- R9 = Useful application of materials

Figure 7: A hypothetical example of using the CBA-AR worksheet for exploring, determining, assessing, and reporting the promotion of CBA in a hypothetical adaptive reuse project

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability: Adaptability Determinants: Functional Convertibility	Adaptability Determinants: Volume Scalability	Adaptability Determinants: Asset Refit-Ability	Interrelated Determinants: Configuration Flexibility	Interrelated Determinants: Product Demountability	Interrelated Determinants: Asset Multi-Usability	Interrelated Determinants: Design Regularity	Circularity Determinants: Material Reversibility	Circularity Determinants: Building Maintainability	Circularity Determinants: Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
Active Strategies	16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1		✕		✕											
	17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1		✕	✕	✕	✕			✕			✓		Demountable lighting fixtures	Demountable ceiling and partitions	PnP cubicles
	18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1						✕					✓			Sharable lounge and seating area	
	19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2										✕	✓	Façade and rooftop PV	Geothermal heat pumps		
	20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2										✕					
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1			✕	✕			✕								
	22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and R3										✕					

Legend: R0- R2 = Smarter product use and manufacture | R3- R7 = Extend life of product and its parts | R8- R9 = Useful application of materials

Figure 7: A hypothetical example of using the CBA-AR worksheet for exploring, determining, assessing, and reporting the promotion of CBA in a hypothetical adaptive reuse project (continue)

Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability: Adaptability Determinants: Functional Convertibility	Adaptability Determinants: Volume Scalability	Adaptability Determinants: Asset Refit-Ability	Interrelated Determinants: Configuration Flexibility	Interrelated Determinants: Product Demountability	Interrelated Determinants: Asset Multi-Usability	Interrelated Determinants: Design Regularity	Circularity Determinants: Material Reversibility	Circularity Determinants: Building Maintainability	Circularity Determinants: Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
Operational Strategies																					
23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1						X											
24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0					X			X	X								
25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1			X			X		X	X		✓		Leasing elevators			
26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and R6								X			✓	Selective dismantling of curtain walls				
27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and R8								X			✓	Sending back the old curtain walls for resue				
28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7								X								
29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and R3						X		X								
30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	R4									X		✓		Adopting MEP maintenance program			
31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	R4 and R5									X							
32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5,S6	Preservation of monumental finishes, doors and windows	R4 and R5								X	X							
33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	R3				X				X								

Legend: R0- R2 = Smarter product use and manufacture; R3- R7 = Extend life of product and its parts; R8- R9 = Useful application of materials

Figure 7: A hypothetical example of using the CBA-AR worksheet for exploring, determining, assessing, and reporting the promotion of CBA in a hypothetical adaptive reuse project (continue)

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