

# Co-Development of a Framework for Circular Building Adaptability in Building Transformation Projects

*A Participatory Research*

Outcomes of a co-creation workshop



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# 1. Summary and Main Outcomes

## 1.1 What is in this report?

This report provides you with main outcomes of the facilitated co-creation workshop on 18-October, 2023 at the Faculty of Architecture and the Built Environment, TU Delft, Delft, the Netherlands. The workshop had mainly a threefold objective, namely *validating* and *collaboratively expanding* the enabling and inhibiting factors to the strategies for a circular and adaptable building transformation, as well as *prioritizing* the strategies according to their effectiveness, feasibility and applicability. However, the workshop started with a reflection on the effectiveness of 2 strategies as well as the formulation of 2 other strategies.

First, this report introduces the underlaying concept of this research – the *circular building adaptability* (CBA) – and its 10 determinants (see [subsection 2.1](#) and [2.2](#)). Second, the refined framework based on outcomes of a previous co-creation workshop, which was organized on 19-April 2023, is presented right after the introduction of the CBA concept (see [subsection 2.3](#)). Third, the outcomes and results of this workshop are presented in [section 3](#). These results include reflection on the effectiveness/formulation of four strategies, validation and expansion of the enabling factors, validation and expansion of the inhibiting factors, and evaluation and ranking of the strategies. It is worth noting that the refined version of the framework based on the outcomes of the second workshop is presented in [section 3](#), under [subsection 3.2](#)

At the beginning of the workshop, all participants were asked to reflect together on the effectiveness of 2 strategies and the formulation of another 2 strategies. It is worth mentioning that the validation and expansion of the factors were carried out in 2 groups, in which the first group focused on the enabling factors while the second group focused on the inhibiting factors. At the end of the workshop, the participants were asked to rate together the strategies in terms effectiveness, economic feasibility and applicability. A 5-point rating scale was used as an evaluation technique. Photos of the participants' reflections on the strategies are provided in the [appendix section](#).

### 1.2 Main Outcomes

The main outcomes can be summarized as follows:

- The participants agreed on the effectiveness of utilizing standardized building products as well as biobased materials in promoting material reversibility. The participants also concluded that utilizing biobased materials is effective to promoting resource recovery.
- The participants rephrased the ninth strategy “decentralization of design” to “compartmentalization of design”, also agreed on rephrasing the fifteenth strategy to “alignment of the building design with the real estate strategy” instead of “alignment of the building design with the property portfolio” .
- The interconnections between the enabling factors and the CBA strategies have been expanded, yet four interconnections have been excluded. Three enabling factors were added to the framework and mapped to many CBA strategies. The newly added enabling factors are location of the project, certification and social acceptance.
- Similarly, the interconnections between the inhibiting factors and the CBA strategies have been expanded, yet six interconnections have been excluded. Two inhibiting factors were added to the framework, namely market fragmentation and lack of ambition. These two inhibiting factors were mapped to the CBA strategies after the workshop by two participants.
- The evaluation of the strategies contributed to getting a better grasp on the effectiveness, economic feasibility and applicability of the strategies. Based on the average of the received rating scores, six strategies can be considered as promising strategies for circular and adaptable building transformation. These strategy are: alignment of the building design with the real estate strategy, utilization of dismountable building components, utilization of renewable energy technologies, utilization of flexible and integrated installations, application of material passports, and provision of shareable facilities.
- Procuring the service of building products as well as utilizing second-hand materials can be seen among the least promising strategies for circular and adaptable building transformation, according the evaluation results.

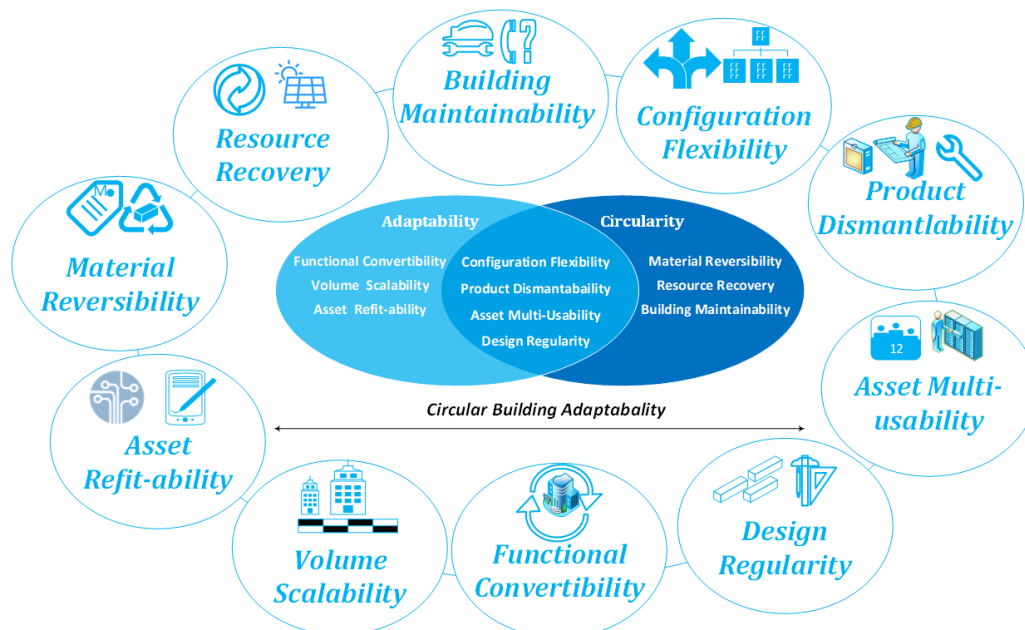
## 2. Overview of the CBA Concept and its Determinants, and the Developed Framework for Circular and Adaptable Building Transformation Projects

### 2.1 What is meant by *Circular Building Adaptability (CBA)*?

Hamida *et al.* (2023a) defined circular building adaptability (CBA) as “the capacity to contextually and physically alter the built environment and sustain its usefulness, whilst keeping the building asset in a closed-reversible value chain.”. CBA was conceptualized in response to the observed limitations with the concept of building circularity to align contextual aspects pertaining to the long-lasting utility of the building assets.

### 2.2 Determinants of *Circular Building Adaptability*

Hamida *et al.* (2023a) expressed CBA with 10 determinants as shown in [Figure 1](#). [Table 1](#) presents a brief description of the CBA determinants (Hamida *et al.* 2023c).



**Figure 1:** Determinants of CBA

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

## 2. Overview of the CBA Concept and its Determinants, and the Developed Framework for Circular and Adaptable Building Transformation Projects

**Table 1:** Description of the CBA determinants

























































Determinant	Brief description
<i>Configuration flexibility</i>	The capacity to reconfigure the layout of spaces without utilising external resources and producing waste.
<i>Product dismantlability</i>	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
<i>Asset multi-usability</i>	The capacity to offer a multiplicity of the use of building assets, so that maximising the efficiency of their utilisation
<i>Design regularity</i>	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
<i>Functional convertibility</i>	The capacity to y to repurpose the function of a building or part of it, so that promoting its longevity while keeping its value
<i>Material reversibility</i>	The capacity to efficiently provide, utilise and reuse the materials in the building within a reversible value chain.
<i>Building maintainability</i>	The capacity to prolong the utility of the building assets and sustain their performance
<i>Resource recovery</i>	The capacity to regenerate the building resources in a manner that reduces the use of new materials and energy consumption
<i>Volume scalability</i>	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.
<i>Asset refit-ability</i>	The capacity to efficiently provide state-of-the-art building assets and technologies, while avoiding waste generation or over-invested solutions.

Source: Hamida *et al.* (2023b)

### 2.3 A Framework for Circular and Adaptable Building Transformation

Figure 2 presents a guiding content-wise framework for circular and adaptable building transformation. It brings together applicable strategies for promoting the CBA determinants along with their enabling and inhibiting factors. This version of the framework was developed based on findings of literature review (Hamida *et al.*, 2023a), case studies (Hamida *et al.*, 2023b), and outcomes of the first part of this participatory study (Hamida *et al.* 2023c).

## 2. Overview of the CBA Concept and its Determinants, and the Developed Framework for Circular and Adaptable Building Transformation

Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors												
		Adaptability Determinants			Interrelated Determinants			Circularity Determinants				Enabling Factors						Inhibiting Factors						
		 Functional Convertibility	 Volume Scalability	 Asset Refit-Ability	 Configuration Flexibility	 Product dismantlability	 Asset Multi-Usability	 Design Regularity	 Material Reversibility	 Building Maintainability	 Resource Recovery	 The building Characteristics	 Collaboration & Partnership/Industrial Symbiosis	 Presence of Motivated/Capable Team	 Economic Viability of Basic Strategies	 New Business Models	 Policy/Legislative Support	 Enabling/Digital Technologies	 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
Passive Strategies	Design Standardization 			✗	✗		✗				✗								✗					
	Separation of the Building Layers (e.g. Separated Walls) 	✗		✗	✗						✗								✗					
	Open the Floor Plan 	✗		✗							✗								✗					
	Provision of Multi-Purpose Spaces 					✗					✗								✗					✗
	Modularization of Spatial Configuration (Layout) 	✗						✗			✗								✗					
	Utilization of Standardized Building Products 							✗			✗								✗					
	Provision of a Core for Building Services 	✗									✗								✗					
	Design for Surplus Capacity 	✗	✗	✗							✗								✗	✗				
	Decentralization of Design 	✗		✗							✗								✗					
	Design for a Mixed Use (Multifunctionality) 	✗									✗		✗				✗			✗	✗			✗
	Utilization of Secondary (Reused/Recycled) Material 								✗		✗		✗	✗			✗		✗	✗	✗	✗	✗	✗
	Utilization of Biobased (Biological) Material 								✗															✗
	Utilization of Circular (Reusable/Recyclable) Material 								✗				✗	✗			✗		✗			✗		✗
Alignment of the Interconnection Between the Floor Plans 		✗																						
Alignment of the Building Design with the Property Portfolio 				✗																				
Active Strategies	Utilization of Adjustable Building Components 	✗		✗																				
	Utilization of Dismountable Building Components 	✗	✗	✗	✗			✗		✗									✗	✗				✗
	Provision of Sharable Spaces 					✗															✗			
	Utilization of Renewable Energy Technologies 									✗							✗							
	Enabling the Use of Natural Lighting/Ventilation 									✗														
	Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play) 			✗	✗			✗																
	Utilization of Water Recovery System 									✗														
Operational Strategies	Provision of Sharable Facilities 					✗					✗													
	Application of (or update of) Material Passports 				✗			✗	✗								✗	✗			✗	✗	✗	
	Procurement of the Service of Building Products 		✗			✗		✗	✗		✗			✗										
	Selective Dismantling 							✗										✗	✗		✗		✗	
	Send Back Discarded Material for Reuse/Recycling 							✗				✗	✗		✗	✗		✗			✗			
	Repurpose Old Building Materials/Products 							✗				✗	✗							✗	✗			
	Product Exchange 					✗		✗				✗	✗								✗			
	Implementation of Proactive/Predictive Maintenance 								✗							✗		✗						
	Repair of Old Building Components 								✗					✗				✗						
	Preservation of Monumental/Old Parts 							✗	✗		✗		✗	✗					✗	✗			✗	
	Utilization of Rented-Second-Hand Products from CE Marketplace 			✗				✗																
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							

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
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**Figure 2:** A guiding framework for circular and adaptable building transformation  
**Source:** Hamida et al. (2023c)

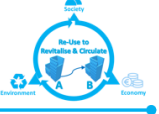
## 3. Workshop Outcomes

### 3.1 Reflection on the effectiveness/formulation of 4 strategies

At the beginning of the workshop, the participants were asked to reflect on the formulation of 2 strategies and the effectiveness of another 2 strategies as shown in [Figure 3](#).

Regarding the formulation of 2 strategies, the participants were asked to reflect on rephrasing the 15<sup>th</sup> strategy *“alignment of the building design with the property portfolio”* to *“alignment of the building design with the property strategy”* because strategy in real estate is more overarching and includes aligning processes, spaces, portfolio and people together. The participants agreed with the proposed amendment, and thus, the strategy has been rephrased to *“alignment of the building design with the real estate strategy”* because also the term “real estate” is often used in practice comparing to the term “property”. Second, the participants were asked to reflect on rephrasing the ninth strategy *“decentralization of design”* as *“decentralization of the building design into independent compartments and systems”*. After in-depth discussions among the participants, they concluded that this strategy can be rephrased to *“compartmentalization of design”*, owing to the fact that the building itself cannot be completely split up into independently physical objects.

#### 4. Reflecting on/Rethinking the Effectiveness/Phrasing of Some Strategies



Together and before dive in the workshop, **let's quickly** go over the following inquiries:

1. **What do you think about the potential contribution or effectiveness of utilizing standardized building products (6<sup>th</sup> strategy) as a strategy to promote “material reversibility”? Can these products contribute to their circularity?**
2. **We realized that the utilization of biobased materials is an essential strategy for the biological flow of material, so we incorporated that in the framework as a passive strategy that contribute to “material reversibility”. Do you agree with that?**
3. **Can we rephrase the strategy the 15<sup>th</sup> strategy, which was added during the first workshop, “alignment of the building design with the property portfolio” to “alignment of the building design with the property strategy”? because a real estate strategy is a comprehensive thing that aligns process, portfolio, and space of a built-property or a property investment**
4. **To clarify the 9<sup>th</sup> strategy “decentralization of design”, can we rephrase it as “decentralization of the building design into independent compartments and systems”?**

TU Delft Department of Building Science and Technology  
BK Bouwkunde 11/15

Figure 3: Asked questions about the effectiveness/formulation of 4 strategies



Regarding the effectiveness of 2 strategies, the participants were asked to first rethink the effectiveness of the sixth strategy *“utilization of standardized building products”* in paving the way for material reversibility. This is owing the fact that research on circularity in buildings indicates that standardization plays a vital role in facilitating circularity in the built environment. The participant agreed with that suggestion, but gave some considerations. For example, some participants indicated that standardization needs to be done in the component level, as this apparently can be more comprehensive and cover more physical assets. In addition, some participants indicated that there might be some sort of physical complexities and limitations with the adoption of this strategy, such as the type, size, location and lifespan of such kind of products. Second, the participant were asked to reflect on a proposal for adding a strategy, called *“utilization of biobased materials”*, as a strategy for promoting material reversibility. This suggestion was proposed as a means to accounts for and incorporate the biological flow of materials in the framework. After some discussions, the participants agreed with this proposal, also concluded that this strategy can also contribute to promoting resource recovery as this kind of materials reduce the use of energy consumption by their regenerative capacity (renewability) in the long term.

#### 3.2 Validation and Expansion of the Enabling and Inhibiting Factors

The validation and expansion of the enabling and inhibiting factors were carried out in a form of group work. As shown in (Figure 4), the participants were divided into two groups. The first group worked on validating and expanding the factors that facilitate the implementation of the CBA strategies, where the second group worked on validating and expanding the factors that hinder or impede the implementation of the CBA strategies.

In each group, the participants were asked to reflect on the previously identified factors in terms of their influence on the implementation of the strategies. Particularly, the participants looked at interrelationships between the factors and the CBA strategies; thereby, accepting the previously built relationships, excluding certain relationships as well as adding and demonstrating new relationships. Finally, each group had the opportunity to add other factors, and then, mapping the newly added factors to the CBA strategies. Figure 5 illustrates the refined version of the framework based on the outcomes of the workshop.


## 5. Your Task as Groups!



- In two groups of 3 to 4 people, spend **30 minutes** to work on the enabling/inhibiting factors (one group for the enablers and the other one for the inhibitors) :
  - Reflect on the relationship we mapped between each strategy and the enabling/inhibiting factors .**
  - Refine the enabling/inhibiting factors if need be.**
  - Expand the enabling/inhibiting factors and their influence on the strategy.**

**Enabling Factors** = factors that facilitate the implementation of the strategies  
**Inhibiting Factors** = factors that hinder the implementation of the strategies

Use the provided **markers** and **yellow sticky notes** to write down your ideas!

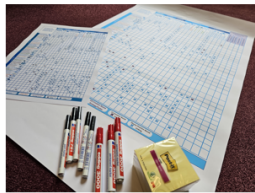
Symbol and Color	Meaning
<b>X</b>	The factor influences the implementation of the strategy
<b>X</b>	Not applicable relationship



Group 1: Enablers

Group 2: Inhibitors





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Figure 4: Instructions for the group activity

#### 3.2.1 Validation and Expansion of the Enabling Factors

According to the outcomes of the collaborative work among members of the first group, it was concluded that the previously included 7 factors are valid. However, the fourth enabling “*economic viability of basic strategies*” factor was rephrased to “*economic feasibility of basic strategies*”. Following are the main outcomes of validating the previously identified enabling factors:

- **The building characteristics:** The participants agreed with previously demonstrated relationship between the building characteristics, as an enabling factor, and many CBA strategies. The collaborative and interactive work among the participants contributed to connecting this factor to another 9 CBA strategies ([Figure 5](#)), namely utilization of biobased materials, utilization of circular (reusable/recyclable) materials, alignment of the interconnection between the floor plans, alignment of the building design with the real estate strategy, utilization of adjustable building components, provision of shareable spaces, utilization of renewable energy technologies, enabling the use of natural lighting/ventilation, and application of (or update of) material passports.

Strategies for Circular Building Adaptability in Adaptive Reuse			Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors																	Evaluation of the Strategies				
			Adaptability Determinants			Interrelated Determinants			Circularity Determinants				Enabling Factors										Inhibiting Factors							Evaluation of the Strategies				
Passive Strategies	1. Design Standardization				✗	✗		✗			✗	✗					✗						✗					✗	✗	4	3	5	4	
	2. Separation of the Building Layers (e.g. Separated Walls)	✗			✗	✗					✗											✗	✗				✗	✗	5	3	4	4		
	3. Open the Floor Plan		✗		✗						✗			✗									✗	✗					4	3	3	3.3		
	4. Provision of Multi-Purpose Spaces						✗				✗			✗	✗							✗	✗				✗		4.5	3	4.5	4		
	5. Modularization of Spatial Configuration (Layout)	✗						✗			✗	✗		✗			✗					✗	✗				✗		4.5	3	4	3.8		
	6. Utilization of Standardized Building Products						✗	✗			✗			✗								✗							3	4	4.5	3.8		
	7. Provision of a Core for Building Services	✗									✗											✗	✗						3	3	3	3		
	8. Design for Surplus Capacity	✗	✗	✗							✗				✗				✗				✗	✗				✗	4	4	3	3.6		
	9. Compartmentalization of Design	✗		✗							✗											✗	✗				✗		4	3	2	3		
	10. Design for a Mixed Use (Multifunctionality)	✗									✗		✗	✗		✗		✗				✗	✗	✗	✗		✗		5	3	2	3.3		
	11. Utilization of Secondary (Reused/Recycled) Materials							✗		✗	✗	✗	✗		✗				✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	5	2	1	2.6		
	12. Utilization of Biobased (Biological) Materials							✗		✗	✗		✗		✗				✗	✗	✗		✗				✗		4	3.5	2	3.1		
	13. Utilization of Circular (Reusable/Recyclable) Materials							✗			✗	✗	✗		✗	✗			✗	✗	✗		✗	✗			✗		5	3.5	2	3.5		
	14. Alignment of the Interconnection Between the Floor Plans		✗								✗															✗			3	3	4	3.3		
	15. Alignment of the Building Design with the Real Estate Strategy				✗						✗						✗											✗		4	4	5	4.3	
Active Strategies	16. Utilization of Adjustable Building Components		✗		✗					✗												✗	✗				✗	✗	4	4.5	3	3.8		
	17. Utilization of Dismountable Building Components		✗	✗	✗	✗		✗		✗	✗	✗										✗	✗			✗	✗	5	4.5	4.5	4.6			
	18. Provision of Shareable Spaces						✗				✗				✗			✗		✗				✗			✗	3	3	5	3.6			
	19. Utilization of Renewable Energy Technologies									✗	✗		✗				✗	✗	✗					✗			✗	3	5	5	4.3			
	20. Enabling the Use of Natural Lighting/Ventilation									✗	✗							✗					✗					4	3	4	3.6			
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			✗	✗			✗															✗	✗				✗	4	5	5	4.6		
	22. Utilization of Water Recovery System									✗									✗				✗	✗			✗	5	3	4	4			
Operational Strategies	23. Provision of Shareable Facilities						✗					✗			✗	✗	✗	✗	✗				✗					✗	5	5	5	5		
	24. Application of (or update of) Material Passports					✗			✗	✗	✗						✗		✗		✗	✗	✗	✗	✗	✗	✗	5	5	3	4.3			
	25. Procurement of the Service of Building Products			✗			✗		✗	✗				✗												✗	✗	4	2.5	2	2.8			
	26. Selective Dismantling								✗			✗	✗		✗	✗					✗	✗	✗	✗	✗	✗		5	2	2.5	3.2			
	27. Send Back Discarded Material for Reuse/Recycling								✗			✗	✗		✗	✗			✗	✗	✗	✗	✗	✗	✗	✗		5	4	3	4			
	28. Repurpose Old Building Materials/Products								✗			✗	✗		✗	✗			✗	✗			✗	✗	✗	✗	✗	5	4	2	3.6			
	29. Product Exchange						✗		✗			✗	✗		✗	✗	✗		✗	✗			✗	✗	✗	✗	✗	5	2	3	3.3			
	30. Implementation of Proactive/Predictive Maintenance								✗						✗		✗					✗		✗			✗	4	4.5	3	3.8			
	31. Repair of Old Building Components								✗				✗			✗	✗					✗	✗	✗		✗	✗	4.5	4	4	4.2			
	32. Preservation of Monumental/Old Parts							✗	✗		✗		✗	✗								✗	✗		✗	✗		4.5	5	2	3.8			
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				✗			✗				✗	✗		✗		✗									✗	✗	✗	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			Excluded Connection by Participants			Revised Text in Workshop 2														

Figure 5: The refined version of the framework based on the outcomes of the workshop

### 3. Workshop Outcomes

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- **Collaboration & partnership/industrial symbiosis:** The participants agreed with previously demonstrated relationship between this enabling factor and 6 CBA strategies (see [Figure 2](#)) . The interactive discussions among the participants contributed to connecting this factor to another 6 CBA strategies ([Figure 5](#)), namely design standardization, modularization of spatial configuration, utilization of dismountable building components, application of (or update of) material passports, selective dismantling, and utilization of rented-second-hand products from CE marketplaces.
- **Presence of motivated/capable team:** Out of 8 previously mapped relationships between this factor and 8 CBA strategies, the participants excluded two relations. The participants excluded that there is an influence of the presence of motivated/capable team on facilitating the design for a mixed-use as well as repair of old building components, although these relations were observed in case studies by Hamida *et al.* (2023b). However, the participants concluded that this enabling factor can facilitate the implementation of 6 strategies ([Figure 5](#)), namely utilization of biobased materials, utilization of dismountable building components, utilization of renewable energy technologies, application of (or update of) material passports, selective dismantling and utilization of rented-second-hand products from CE marketplaces.
- **Economic feasibility of basic strategies:** This enabling factor was already linked to two CBA strategies, namely utilization of secondary materials and preservation of monumental/old parts. The participants agreed on those two relationships, also expanded them by relating this enabling factor to another five strategies ([Figure 5](#)), namely open the floor plan, provision of multi-purpose spaces, modularization of spatial configuration, utilization of standardized building products, and design for a mixed-use.

- **New business models:** This enabling factor was already linked to three CBA strategies, namely procurement of the service of building products, send back discarded materials for reuse/recycling, and implementation of proactive/predictive maintenance. The participants perceived this enabling factor as an important enabler for implementing many CBA. The participants related this enabling factor to 11 CBA strategies ([Figure 5](#)), namely provision of multi-purpose spaces, design for surplus capacity, utilization of biobased materials, utilization of circular (reusable/recyclable) materials, provision of shareable spaces, provision of shareable facilities, selective dismantling, repurpose old building materials/products, product exchange, repair of old components, and utilization of rented-second-hand products from CE marketplaces. However, the participants pointed out that the effectiveness of new business models differs per the perspective of the stakeholder, such as design team, building owner and investors.
- **Policy/legislative support:** This enabling factor was already linked to 4 CBA strategies, namely: design for a mixed-use, utilization of secondary materials, utilization of circular (reusable/recyclable) materials, and send back discarded materials for reuse/recycling. The participants excluded that support from legislation or policies can facilitate the design for a mixed use. On the other hand, the participants linked this enabling factor to another 5 CBA strategies ([Figure 5](#)), namely provision of shareable facilities, selective dismantling, repurpose old building materials/products, product exchange, and repair of old components.
- **Enabling/digital technologies:** Enabling and digital technologies (e.g. BIM and IoT) have shown to be an effective means to implement three CBA strategies, namely utilization of renewable energy technologies, application of (or update of) material passports, and implementation of proactive/predictive maintenance. In the workshop, the participants concluded that they can also facilitate implementing another 6 CBA strategies ([Figure 5](#)), namely design standardization, modularization of spatial configuration, alignment of the building design with the real estate strategy, provision of shareable facilities, product exchange, and utilization of rented-second-hand products from CE marketplaces.

### 3. Workshop Outcomes

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The participants added another three enabling factors, namely location of the project, certification and social acceptance. Furthermore, the participants linked those enabling factors to many of the CBA strategies ([Figure 5](#)). Following are the outcomes of mapping the newly added enabling factors to the CBA strategies:

- **Location of the project:** The participants perceived the location of the project as an enabler for 5 CBA strategies, namely design for surplus capacity, design for a mixed use, provision of shareable spaces, utilization of renewable energy technologies and provision of shareable facilities.
- **Certification:** The participants considered sustainability certification and rating systems, such as BREEAM, as an essential enabler for 11 CBA strategies by the means of evaluation. The 11 strategies are: utilization of secondary materials, utilization of circular (reusable/recyclable) materials, utilization of biobased materials, utilization of renewable energy technologies, enabling the use of natural lighting/ventilation, utilization of water recovery system, provision of shareable facilities, application of (or update of) material passports, send back discarded materials for reuse/recycling, repurpose old building materials/products, and product exchange.
- **Social acceptance:** The participants arrived at a conclusion that social acceptance, as a society-related factor, plays a significant role in the implementation of 9 out of 33 CBA strategies, including utilization of secondary materials, utilization of circular (reusable/recyclable) materials, utilization of biobased materials, provision of shareable spaces, utilization of renewable energy technologies, provision of shareable facilities, send back discarded materials for reuse/recycling, repurpose old building materials/products, and product exchange.

#### 3.2.2 Validation and Expansion of the Inhibiting Factors

It has been concluded that the previously included 6 inhibiting factors are valid according to the outcomes of the collaborative work among members of the second group. Similar to the enabling factors, this group expanded and mapped many relationships between the inhibiting factors and many of the CBA strategies while excluding some relationships ([Figure 5](#)). Following are the main outcomes of validating the previously identified inhibiting factors:

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- **Lack of expertise:** The interactive discussions among the participants resulted in excluding that lack of expertise hinder 4 CBA strategies ([Figure 5](#)), namely utilization of secondary materials, utilization of circular (reusable/recyclable) materials, selective dismantling and repair of old building components. The participants justified the exclusion of these relationships by the fact that these strategies are already implemented in practice but less adopted in the real world because of lack of flexible or innovative mindsets, so not because of lack of experts. As these relationships were already manifested in previous case studies (Hamida *et al.*, 2023b), the researchers of this study will discuss the outcomes further with the participants and other experts. It is worth noting that this factor was perceived as an inhibitor to the application of (or update of) material passports in the previous workshop. However, the participants in this workshop perceived lack of expertise as an inhibitor that impedes another three CBA strategies, namely design for a mixed use (multifunctionality), utilization of biobased materials, and send back discarded materials for reuse/recycling.
- **Technical complexities with building products/materials:** This inhibiting factor was perceived as an inhibitor to implementing 14 CBA strategies, based on outcomes of literature review and case studies ([Figure 2](#)). Out of the 14 relationships, the participants excluded the influence of this factor on hindering 3 CBA strategies, namely open the floor plan, provision of multi-purpose spaces, and modularization of spatial configuration ([Figure 5](#)). The participants supported these exclusions with the argument that these three strategies are technically complex, but cannot be greatly hindered by the technical complexities with building products/materials. On the other hand, the participants considered this factor as an obstacle to the implementation of another 8 CBA strategies, namely design for a mixed use, utilization of adjustable building components, utilization of flexible and integrated installations, utilization of water recovery system, application of (or update of) material passports, repurpose old building materials/products, product exchange, and repair of old building components. Regarding the application of (or update of) material passports, a participant also indicated that there is a difficulty with adding information on the technical complexity of materials to material passports.



### 3. Workshop Outcomes

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- **Economic infeasibility of innovative strategies:** The results of literature review, case studies and the first workshop resulted in mapping this inhibiting factor to 6 CBA strategies ([Figure 5](#)), namely design for surplus capacity, design for a mixed use, utilization of secondary materials, utilization of dismountable building components, repurpose old building materials/products, and preservation of monumental/old parts. In this workshop, the participants arrived at a conclusion that the economic infeasibility of innovation in strategies has a direct bearing on hinder the implementation of many CBA strategies. Thus, the outcomes of the interactive discussions among the participants resulted in linking this inhibitor to 20 CBA strategies, namely separation of the building layers, open the floor plan, provision of multi-purpose spaces, modularization of spatial configuration, provision of a core for building services, compartmentalization of design, utilization of biobased materials, utilization of circular (reusable/recyclable) materials, utilization of adjustable building components, utilization of renewable energy technologies, enabling the use of natural lighting/ventilation, utilization of flexible and integrated installations, utilization of water recovery system, provision of shareable facilities, application of (or update of) material passports, selective dismantling, send back discarded materials for reuse/recycling, product exchange, implementation of proactive/predictive maintenance, and repair old building components.
- **Tendency to follow traditional paradigms:** The findings of theoretical and empirical studies in this project pointed out that this inhibiting factor impedes 9 CBA strategies ([Figure 5](#)), namely design for a mixed use, utilization of secondary materials, utilization of circular (reusable/recyclable) materials, provision of shareable spaces, application of (or update of) material passports, selective dismantling, send back discarded materials for reuse/recycling, repurpose old building materials/products, and product exchange. The participants agreed with these findings; nevertheless, no additional relationships were demonstrated by the participants. The participants of this group arrived at a consensus that there is an interrelationship between this inhibiting factor and the previous one – economic infeasibility of innovative strategies. They argued that innovative solutions can be feasible when they are researched in practice.



- **Lack of data and warranty on old materials:** Based on the findings of two studies in this projects, lack of data and warranty was linked perceived as an inhibiting factor to the implementation of only three CBA strategies ([Figure 5](#)), namely utilization of secondary materials, application of (or update of) material passports, and preservation of monumental/old parts. However, the results of the interactive discussions among members of the second group indicated that this inhibiting factor is significant in terms of its potential to hinder the implementation of many CBA strategies. In this regard, the participants considered this inhibiting factor as an obstacle to another 8 CBA strategies, namely alignment of the interconnection between the floor plans, selective dismantling, send back discarded materials for reuse/recycling, repurpose old building materials/products, product exchange, implementation of proactive/predictive maintenance, repair old building components, and utilization of rented-second-hand products from CE marketplaces.
- **Legal and legislative restrictions:** Based on the findings of literature review, case studies and first workshop, this inhibiting factor was considered to be an inhibitor to implementing 8 CBA strategies, namely provision of multi-purpose spaces, design for a mixed use, utilization of secondary materials, utilization of biobased materials, utilization of circular (reusable/recyclable) materials, utilization of dismountable building components, application of (or update of) material passports and selective dismantling. Regarding the application of (or update of) material passports, the participants corroborate this relationship by indicating that applying material passports cannot be fostered as long as it is not mandatory. The outcomes of this workshop indicate that legal and legislative restrictions constitute a major obstacle to the implementation of CBA strategies in building transformation projects, as the participants linked this inhibiting factor to another 10 CBA strategies: open the floor plan, modularization of spatial configuration, design for surplus capacity, compartmentalization of design, provision of shareable spaces, send back discarded materials for reuse/recycling, repurpose old building materials/products, product exchange, preservation of monumental/old parts, and utilization of rented-second-hand products from CE marketplaces.

### 3. Workshop Outcomes

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The participants indicated that there are some missing aspects pertaining to the location, environment, perspectives and cultures. The participants added another two inhibiting factors, namely market fragmentation and lack of ambition. However, the participants did not link both factors to any CBA strategy. Therefore, the participants were contacted after the workshop to link both factors to the CBA strategies. Out of 5 members of the second group, two participants responded and linked the two factors to the CBA strategies as follows:


- **Market fragmentation:** As an inhibiting factor, market fragmentation was linked to 14 CBA strategies ([Figure 5](#)), namely design standardization, separation of the building layers, utilization of secondary materials, utilization of adjustable building components, utilization of dismountable building components, utilization of flexible and integrated installations, utilization of water recovery system, application of (or update of) material passports, procurement of the service of building products, repurpose old building materials/products, product exchange, implementation of proactive/predictive maintenance, repair old building components, and utilization of rented-second-hand products from CE marketplaces.
- **Lack of ambition:** This factor was perceived as an inhibitor to 25 CBA strategies ([Figure 5](#)), namely design standardization, separation of the building layers, provision of multi-purpose spaces, design for surplus capacity, compartmentalization of design, design for a mixed use, utilization of secondary materials, utilization of biobased materials, utilization of circular (reusable/recyclable) materials, alignment of the building design with the real estate strategy, utilization of adjustable building components, utilization of dismountable building components, provision of shareable spaces, utilization of renewable energy technologies, utilization of flexible and integrated installations, utilization of water recovery system, provision of shareable facilities, application of (or update of) material passports, procurement of the service of building products, selective dismantling, repurpose old building materials/products, product exchange, implementation of proactive/predictive maintenance, repair old building components, and utilization of rented-second-hand products from CE marketplaces. However, one participant pointed out that the lack of ambition could impede the implementation of these 25 strategies but not completely inhibit them.



#### 3.4 Ranking and Prioritization of the Strategies

The participants were asked to collectively assess each CBA strategy in terms of its effectiveness in promoting CBA, applicability in practice and economic feasibility by giving a score ranging from 1 to 5 to each criterion. **Figure 6** illustrates the given instructions on the evaluation. Based on the given scores, an overall score was calculated by taking the average of the three scores. To make a qualitatively simplistic interpretation of the scores, **Table 2** presents an adopted scale for the used 5-points rating scheme. For each CBA strategy, the calculated average score represents an indicator of its acceptability level.

## 6. Evaluating the strategies (together)

- From 1 to 5, let's evaluate the strategies and give them a score in terms of :
  - Effectiveness in promoting CBA in adaptive reuse**
  - Applicability in practice.**
  - Economic Feasibility**
  - Overall score (average)**





13/15

**Figure 6:** Instructions for evaluating the strategies

**Table 2:** The adopted rates for the used 5-points evaluation scale

Scale	Evaluation criterion			
	Effectiveness in promoting CBA	Applicability in practice	Economic feasibility	Acceptability level (average of 3 scores)
4 – 5	Extremely effective	Extremely applicable	Entirely feasible	Highly acceptable
3 – 3.9	Very effective	Very applicable	Quite feasible	Very acceptable
2 – 2.9	Effective	Applicable	Feasible	Acceptable
1 – 1.9	Somewhat effective	Somewhat applicable	Barely feasible	Fairly acceptable
0 – 0.9	Not effective	Not applicable	Not feasible	Not acceptable

### 3. Workshop Outcomes

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Regarding the effectiveness of the strategies in promoting CBA, the results of the evaluation indicate that the effectiveness of the 33 CBA strategies is “extremely effective” as shown in [Figure 5](#) and in accordance with the adopted interpretation metrics in [Table 2](#).

The applicability of the strategies in practice varied, as the results indicated that it ranges between “applicable” and “extremely applicable”. However, the majority of the strategies have been perceived either “very applicable” or “extremely applicable”, as shown in [Figure 5](#). The results points out that 5 strategies have been perceived as “applicable”, 14 “very applicable”, and 14 “extremely applicable”, respectively.

The evaluation of the CBA strategies in terms of their economic feasibility indicate that the majority of them are economically feasible. As shown in [Figure 5](#) and according to the adopted interpretation metrics in [Table 2](#), only one strategy have been perceived as “barely feasible”, while the other 32 strategies have been considered as “feasible”, “quite feasible” or “entirely feasible”. Out of the 32 economically feasible CBA strategies, 8 strategies have been perceived as “feasible”, 9 “quite feasible” and 15 “entirely feasible”, respectively.

Based on the calculated average of the 3 given scores to each CBA strategy, the findings indicate that the acceptability level of the 33 CBA strategies ranges between “acceptable” and “highly acceptable” ([Figure 5](#)). Out of the 33 CBA strategies, only two strategies are considered to be “acceptable”, while the acceptability level of the other 31 strategies ranges between “very acceptable” (19 strategies) and “highly acceptable” (12 strategies). As an initial prioritization, and based on the average of the three scores, utilization of dismountable building products, utilization of flexible and integrated installations and provision of shareable facilities can be seen as the most acceptable 3 CBA strategies.

## 4. Appendix: Photographs

*Handwritten notes on the photograph:*

- Top Left:** "Natural Assets. If we can utilize them over there"
- Top Center:** "The building characteristics: Design, Quality, Building name, location"
- Top Right:** "Other Enabling Factors: Location of the building, Certification, Social acceptance"
- Left Margin:** "strategies influence each other"
- Bottom Left:** "Combine"
- Bottom Center:** "32 is enabling factor"

Strategies for Circular Building Adaptability in the Reuse		Determinants of Circular Building Adaptability										Enabling Factors		Other Enabling Factors	
		Adaptability Determinants			Interrelated Determinants			Circularity Determinants				Enabling Factors		Other Enabling Factors	
		Functional Convertibility	Volume Scalability	Asset Reft-Ability	Configuration Flexibility	Product dismantability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building characteristics	Enabling Factors		
1. Design Standardization															
2. Separation of the building layers (e.g. Separation of walls)															
3. Design of the Floor Plan															
4. Provision of Multi-Purpose Spaces															
5. Modularization of Spatial Configuration (Layout)															
6. Utilization of Standardized Building Products															
7. Provision of a Core for Adding Services															
8. Design for Surplus Capacity															
9. Decentralization of Design															
10. Design for a Mixed Use (Multifunctionality)															
11. Utilization of Secondary (Reused/Recycled) Material															
12. Utilization of Biobased (Biological) Material															
13. Utilization of Circular (Reusable/Recyclable) Material															
14. Alignment of the Interconnection Between the Floor Plans															
15. Alignment of the Building Design with the Property Portfolio															
16. Utilization of Adjustable Building Components															
17. Utilization of Dismountable Building Components															
18. Provision of Shareable Spaces															
19. Utilization of Renewable Energy Technologies															
20. Enabling the Use of Natural Lighting/Ventilation															
21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)															
22. Utilization of Water Recovery System															
23. Provision of Shareable Facilities															
24. Application of (or update of) Material Passports															
25. Procurement of the Service of Building Products															
26. Selective Dismantling															
27. Send Back Discarded Material for Reuse/Recycling															
28. Repurpose Old Building Materials/Products															
29. Product Exchange															
30. Implementation of Proactive/Predictive Maintenance															
31. Repair of Old Building Components															
32. Preservation of Monuments/Old Parts															
33. Utilization of Rented/Second-Hand Products from CE Marketplace															

**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

Outcomes of validating and expanding the enabling factors



## 4. Appendix: Photographs

Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability										Inhibiting Factors					Other Inhibiting Factors							
		Adaptability Determinants			Interrelated Determinants			Circularity Determinants				Inhibiting Factors					Other Inhibiting Factors							
		Functional Convertibility	Volume Scalability	Asset Re-fit Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	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	Fragility of Old Building	Lack of Adaptation					
Passive Strategies	1. Design Standardization				✗	✗		✗				✗												
	2. Separation of the Building Layers (e.g. Separated Walls)		✗		✗	✗						✗	✗											
	3. Open the Floor Plan		✗		✗							✗	✗				✗							
	4. Provision of Multi-Purpose Spaces						✗					✗	✗			✗								
	5. Modularization of Spatial Configuration (Layout)	✗						✗				✗	✗			✗								
	6. Utilization of Standardized Building Products							✗				✗	✗											
	7. Provision of a Core for Building Services	✗										✗	✗											
	8. Design for Surplus Capacity	✗	✗	✗								✗	✗				✗							
	9. Decentralization of Design	✗		✗								✗	✗				✗							
	10. Design for a Mixed Use (Multifunctionality)	✗										✗	✗	✗	✗		✗							
Active Strategies	11. Utilization of Secondary (Reused/Recycled) Material							✗		✗	✗	✗	✗	✗	✗	✗	✗							
	12. Utilization of Biobased (Biological) Material							✗			✗	✗	✗			✗								
	13. Utilization of Circular (Reusable/Recyclable) Material							✗			✗	✗	✗	✗	✗	✗								
	14. Alignment of the Interconnection Between the Floor Plans		✗																					
	15. Alignment of the Building Design with the Property Portfolio				✗										✗									
	16. Utilization of Adjustable Building Components		✗		✗							✗	✗											
	17. Utilization of Dismountable Building Components		✗	✗	✗	✗		✗				✗	✗			✗								
	18. Provision of Shareable Spaces						✗							✗		✗								
	19. Utilization of Renewable Energy Technologies										✗		✗											
	20. Enabling the Use of Natural Lighting/Ventilation										✗		✗											
Operational Strategies	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			✗	✗		✗				✗	✗												
	22. Utilization of Water Recovery System									✗		✗	✗											
	23. Provision of Shareable Facilities					✗							✗											
	24. Application of (or update of) Material Passports				✗			✗	✗		✗	✗	✗	✗	✗	✗								
	25. Procurement of the Service of Building Products		✗			✗		✗	✗															
	26. Selective Dismantling							✗			✗	✗	✗	✗	✗	✗								
	27. Send Back Discarded Material for Reuse/Recycling							✗			✗	✗	✗	✗	✗	✗	✗							
	28. Repurpose Old Building Materials/Products							✗				✗	✗	✗	✗	✗	✗							
	29. Product Exchange					✗		✗				✗	✗	✗	✗	✗	✗							
	30. Implementation of Proactive/Predictive Maintenance								✗		✗		✗			✗								
	31. Repair of Old Building Components								✗		✗	✗	✗			✗								
	32. Preservation of Monumental/Old Parts							✗	✗			✗	✗			✗	✗							
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				✗			✗								✗	✗							
Legend		Literature-Based Strategy/Factor		Literature- and Practice-Based Strategy/Factor		Practice-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		Co-Creation-Based Strategy/Factor		

Outcomes of validating and expanding the inhibiting factors

## 4. Appendix: Photographs

Strategies for Circular Building Adaptability in Adaptive Reuse	Determinants of Circular Building Adaptability									Enabling and Inhibiting Factors									Evaluation of the Strategies							
	Adaptability Determinants			Interrelated Determinants			Circularity Determinants			Enabling Factors					Inhibiting Factors				Effectiveness of the Strategy in Promoting CBA		Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)			
	Functional Convertibility	Volume Scalability	Asset Reconfigurability	Long-Term Viability	Product Convertibility	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	Building Characteristics	Collaboration & Partnership	Presence of Motivated Stakeholders	Economic Viability of Reuse Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Lack of Expertise	Technical Complexities with Building Productivity Materials	Economic Infeasibility of Reuse Strategies	Traditional Paradigms	Lack of Data and Awareness on Old Materials		Legal and Legislative Restrictions		
Passive Strategies	1. Design Standardization																							4	3	5
	2. Separation of the Building Layers (e.g. Separated Walls)																							5	3	4
	3. Open the Floor Plan																							4	3	3
	4. Provision of Multi-Purpose Spaces																							4	5	3
	5. Modularization of Spatial Configuration (Layout)																							4	5	3
	6. Utilization of Standardized Building Products																							3	4	4
	7. Provision of a Core for Building Services																							3	3	3
	8. Design for Surplus Capacity																							4	4	3
	9. Decentralization of Design																							4	3	2
	10. Design for a Mixed Use (Multi-Functioning)																							5	3	2
Active Strategies	11. Utilization of Secondary (Reused/Recycled) Material																							5	2	1
	12. Utilization of Biobased (Biological) Materials																							4	3	2
	13. Utilization of Circular (Reusable/Recyclable) Material																							5	3	2
	14. Alignment of the Interconnection Between the Floor Plans																							3	3	4
	15. Alignment of the Building Design with the Property Portfolio																							4	4	5
	16. Utilization of Adjustable (Reconfigurable) Components																							4	4	3
	17. Utilization of Dismountable Building Components																							5	4	5
	18. Provision of Shareable Spaces																							3	3	5
	19. Utilization of Renewable Energy Technologies																							3	5	5
	20. Enabling the Use of Natural Lighting/Ventilation																							3	5	5
Operational Strategies	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)																							4	5	5
	22. Utilization of Water Recovery System																							5	3	4
	23. Provision of Shareable Facilities																							6	5	5
	24. Application of (or update of) Material Passports																							5	5	3
	25. Procurement of the Service of Building Products																							4	5	2
	26. Selective Dismantling																							5	2	5
	27. Send Back Discarded Material for Reuse/Recycling																							5	4	3
	28. Repurpose Old Building Materials/Products																							5	4	2
	29. Product Exchange																							5	2	3
	30. Implementation of Proactive/Predictive Maintenance																							4	5	3
Operational Strategies	31. Repair of Old Building Components																							4	5	4
	32. Preservation of Monumental/Old Parts																							4	5	4
	33. Utilization of Rented-Second-Hand Products from CE Marketplace																							4	5	2
Over all Score (Average)																							4	5	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

Outcomes of evaluating the CBA strategies

## References

- Hamida, M.B., Jylhä, T., Remøy, H. and Gruis, V. (2023a), "Circular building adaptability and its determinants – A literature review", *International Journal of Building Pathology and Adaptation*, Vol. 41 No. 6, pp. 47-69. <https://doi.org/10.1108/IJBPA-11-2021-0150>
- Hamida, M.B., Remøy, H., Gruis, V. and Jylhä, T. (2023b), "Circular building adaptability in adaptive reuse: multiple case studies in the Netherlands", *Journal of Engineering, Design and Technology*. <https://doi.org/10.1108/JEDT-08-2022-0428>
- Hamida, M.B., Remøy, H., Gruis, V., and van Laar, B. (2023c), "Co-Development of a framework for circular building adaptability in adaptive reuse: A participatory study", In *Proceedings of the International Conference "Sustainable Built Environment and Urban Transition"*, Linnaeus University, Växjö, Sweden. <https://open.lnu.se/index.php/sbut/article/view/3813>