Rapport de recherche

Bâtiments adaptables et démontables

Équipe solution #6

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Le lab construction est un projet du Centre d'études et de recherches intersectorielles en économie circulaire de l'ÉTS (CERIEC).

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1. Introduction

Le laboratoire d'accélération en économie circulaire pour le secteur de la construction (le Lab construction), porté par le CERIEC, a pour mission de démontrer, par des projets d'expérimentation innovants et cocréés avec les parties prenantes, comment intégrer puis généraliser des stratégies d'économie circulaire (ÉC) dans le secteur de la construction au Québec.

Dans ce cadre, des ateliers de travail ont permis de faire émerger une vision d'un secteur de la construction circulaire, puis d'identifier et de prioriser les freins à l'économie circulaire pour le secteur et enfin d'imaginer des solutions pour lever ces freins. Cette démarche a été menée en cocréation avec l'ensemble des parties prenantes du secteur, issues du milieu académique et du secteur privé et institutionnel.

Suite à l'identification des solutions, une équipe s'est réunie autour de la solution intitulée 'Bâtiments adaptables et démontables - principes de conception et feuille de route pour l'industrie de la construction au Québec', afin de développer un projet d'expérimentation autour de cette solution – ce projet fait l'objet du présent document.

Lors des séances de co-création, les freins suivants ont été identifiés:

- Les clients, donneurs d'ouvrage et soumissionnaires sont peu informés et accompagnés en termes d' EC, ce qui nuit à son adoption.
- Manque de critères, d'accompagnement et d'outils pour intégrer l'EC dans les contrats
- Matériaux choisis et assemblés de manière à ne pas faciliter l'adaptation ou le démontage dans le temps
- Peu de préfabrication et déconstruction non courante
- Peu d'outils pour le démontage
- Peu d'interaction entre les acteurs de la chaîne de valeur
- Manque d'incitatifs pour réutiliser un bâtiment, que ce soit en partie ou dans son ensemble (incluant ses composantes et matériaux)
- Manque d'expertise en lien avec le recensement et traçabilité des matériaux

Le présent projet vise à contribuer à éliminer ou diminuer l'effet de ces freins et ainsi contribuer à la mise en œuvre opérationnelle des principes de conception favorisant des bâtiments adaptables et démontables. Ceci est un facteur clé dans la transition du secteur de la construction vers une économie circulaire

2. Le projet de recherche

Les approches de conception en vue de l'adaptabilité et du démontage sont bien documentées en tant que principes, qu'il s'agisse de Design for Disassembly (DfD) ou de Design for Manufacture and Assembly (DfMA). Leurs bénéfices semblent clairs, notamment en termes de réduction des matières résiduelles générées et d'économies de ressources vierges à mobiliser ; à ce titre ces approches contribuent directement à la mise en œuvre d'une économie circulaire pour le secteur de la construction. Cependant leur opérationnalisation est encore très peu répandue, notamment par manque d'outils concrets pour les mettre en œuvre. Ainsi, des critères possibles de conception en vue de l'adaptabilité et du démontage (déconstruction) pourraient constituer une boîte à outils pertinente pour mettre en œuvre ces stratégies de conception. Le but final du présent projet est d'établir une feuille de route pour l'ensemble des parties prenantes (donneurs d'ouvrage, concepteurs, constructeurs, chaînes d'approvisionnement) de façon à favoriser l'inclusion généralisée des principes d'une théorie globale de conception en vue de l'adaptabilité et du démontage des projets de construction. Nous proposons alors un nouvel acronyme : DfAD – Design for Adaptability and Disassembly).

2.1. Objectifs

1. Cartographier le domaine à partir de la littérature scientifique et des meilleures pratiques
2. Construire un cadre conceptuel pour expliciter les principes, variables et contextes d'application des stratégies d'adaptation et de démontage (déconstruction)
3. Développer un outil d'évaluation opératoire du potentiel d'adaptation et de démontage (déconstruction) pour les étapes d'élaboration d'un projet (conception et pré-construction)
4. Préparer une feuille de route pour l'industrie de la construction et pour les donneurs d'ouvrage publics

2.2. Méthodologie

La recherche a utilisé la méthodologie de Design Science Research, qui vise à répondre à un problème de l'industrie en développant un 'artéfact' (voir la figure-1).

Dans le cadre de cette recherche, les étapes suivantes ont été réalisées :

- Exploratoire – revue de la littérature et des meilleures pratiques sur le sujet dans le monde
- Entrevues avec des expertes locaux – pour définir les besoins et les pratiques dans le contexte local
- Étude de cas – pour obtenir plus d'information concrète et détaillée sur des projets de bâtiments adaptables
- Développement constructiviste – définition d'un cadre conceptuel pour la conception de bâtiments adaptables
- Un début de validation de ce cadre conceptuel a été amorcé par son application sur des projets réels venant du contexte local.

Dû aux contraintes de temps, le projet sera continué dans le cadre de la suite de la recherche doctorale de Saba Baienat, ainsi que dans le contexte d'un projet avec un partenaire institutionnel – la SQI, qui aimerions développer un processus d'opérationnalisation du cadre opérationnel. De cette façon, notre équipe sera en mesure d'adresser le dernier livrable du projet – la rédaction d'un guide d'application du principe DfAD pour les donneurs d'ouvrage publics.

3. Revue de la littérature

The literature review is structured into three distinct sections. The initial segment delves into the foundational theories underpinning design for adaptability, highlighting how it diverges from the concept of flexibility. The second section of the review presents three key frameworks related to the adaptability of buildings, acknowledging the existence of additional theories but focusing specifically on these three. Lastly, the third section explores methods of evaluation, specifically discussing approaches to assess a building's adaptability.

3.1. Main concepts used for adaptability of buildings

As the effects of climate change became felt around the world, there has been an increasing global and local focus on strategies that address the causes of climate change. Moreover, the demand for energy, land and materials resulting from new developments needs to be tempered by taking better care of existing buildings, extending their life expectancy and using less energy (Conejos et al., 2014). Permanently buildings are designed as statistic assets objects, reflecting the one constant scenario in mind of defined form, function, and performance (Askar, Bragança, & Gervásio, 2021) Since changes are an inevitable part of our lives, adaptable architecture provides thought-provoking insights into how we can prolong the useful life of buildings by designing them to be more adaptable and creating a more sustainable built environment (Schmidt III & Austin, 2016). The adaptability of the building increases the possibility of changes in the buildings based on user's need with the minimum amount of disruption (Kamara et al., 2020). Furthermore, the response to change should be with little penalty in time, effort, cost or performance (Gosling et al., 2013). Adaptability tries to address the three pillars of sustainability - economic, environmental, and social, by saving materials and costs, reviving neighbourhoods, decreasing obsolescence and avoiding demolition. Therefore, an adaptable building can also provide a comfort zone and cost-effective living for occupants. The adaptability of buildings is being investigated by many researchers and some strategies and frameworks are proposed recently. There is a lot of overlapping between the existing frameworks, and it is necessary to review them though roughly to propose a new model for future uses. While some of these models are based on previous efforts, others have conceptualized new models.

3.1.1. Adaptability vs. flexibility

The term 'Change' is the most common thread that runs through different definitions of the adaptability (Pinder et al., 2017). Change in buildings can be unpredictable and it is important to understand how buildings respond to such modifications. This provides insights and makes the prediction of changes more possible in future (Kamara et al., 2020). Confusion about the meaning of adaptability is exacerbated by the fact that authors use terminology in different ways. For instance, some authors treat the terms "adaptability" and "flexibility" as synonyms, and others make a distinction between the two concepts, but often in conflicting ways The conceptual framework by Leaman (1962) proposed to better understand the changes over time. According to this author, the ability of the building for quick changes with high frequency is considered flexibility and for long-term with low frequency is named adaptability Figure 1.

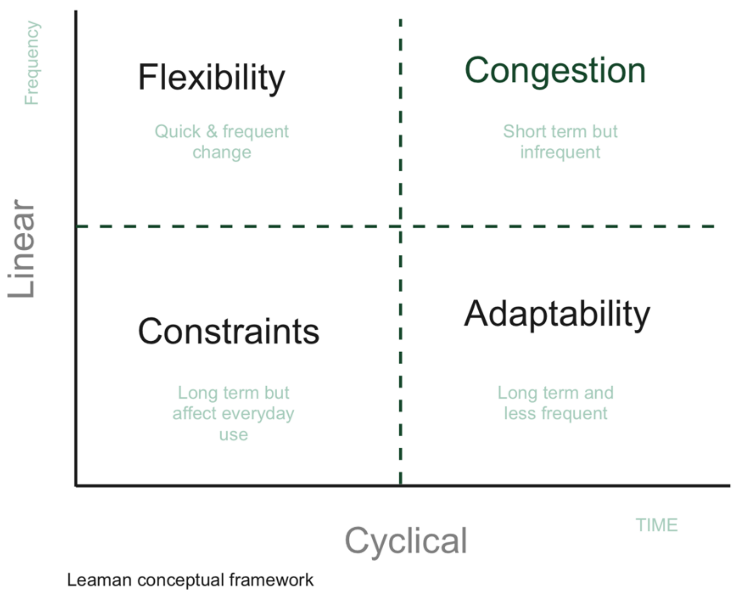


Figure 1 Frequency of changes in a building over time (adapted from Leman, 1962)

3.1.2. Main theories for supporting building adaptability

To analyze the proposed frameworks and theories of adaptability, it is necessary to start with John Habraken's theory (1962). The main principles of this theory considered the structure of the buildings into supports and infills. The supports provide the basic infrastructure with a permanent lifespan while the infill's life expectancy is shorter and more adaptable (Schneider & Till, 2005). The approach of this theory provided adaptability by improving the adjustability, flexibility and refitability of the building. Based on this approach, Duffy (1990) proposed the 'shearing layers' theory. Duffy stated, "*A building properly conceived is several layers of longevity of built components.''* (Brand, 1995*)*. Duffy identified four 'shearing' layers for buildings including shell (structure), service (e.g. heating, piping), and set (e.g. furniture). Another important criterion in the shearing layer model is time - identifying each layer with its own lifetime to show the frequency of changes. Later, Brand (1994) added two other layers to Duffy's model. It is a "6'S" layers concept with service, structure, skin, space plan and stuff Figure 2Tableau 1.

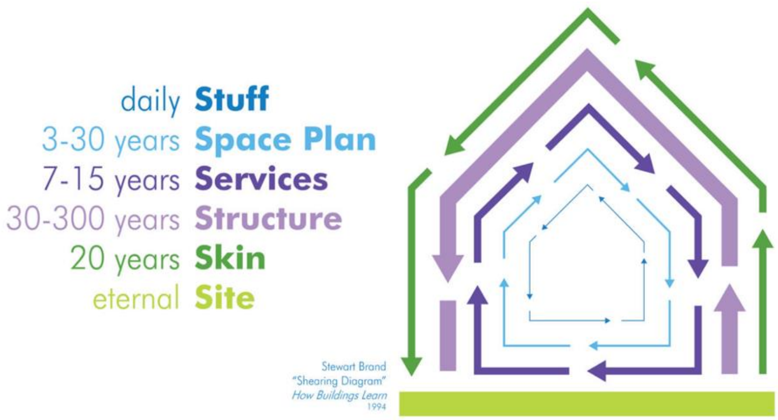


Figure 2 Shearing diagram, adapted from Steward Brand 1994

Layer	Description	Time scale
Site	Geographic setting	Eternal
Structure	Load bearing elements	30-300 years
Skin	Facade	20 years
Services	Plumping, HVAC	7-15 years
Space plan	Furniture, equipment position	3-30 years
Stuff	Furniture, equipment position	Daily

Tableau 1: provides a comparison between the models of Habraken, Duffy and Brand.

3.2. Adaptable buildings frameworks

The Adaptable Building Framework is an innovative concept in architecture and building design that emphasizes flexibility and adaptability in the construction and use of buildings. This framework allows buildings to be easily modified or repurposed over time to meet changing needs, without requiring extensive renovations or reconstructions. It incorporates modular designs, interchangeable parts, and versatile spaces that can evolve according to the changing requirements of its occupants or the environment. This approach contributes to the adaptability of buildings by enabling them to respond to changing social, technological, and environmental conditions more efficiently.

3.2.1. Adaptability Core Concept Model

To categorize different kinds of changes in buildings over time, the 'Core concept model'(CCM) . introduced six main types of changes Figure 3. movable location, adjustable task, versatile space, refillable performance, convertible function and scalable size. In addition, for each type of change, the author proposed design tactics (dark grey text). Stakeholder benefits are written in lighter grey text and the definition of adaptability is seen at the core of the concept. If we move clockwise, the frequency of changes is relatively variable from high and daily (adjustable task) to low frequency which may happen over a decade (movable location) (Beadle, Gibb, Austin, Fuster, & Madden, s.d.). Indeed, Tableau 2 shows a short definition for each type of change with some relevant examples. In some research modifications of buildings are divided into two main categories: user-driven modifications that do not disturb the fabric of the building and others - which becomes active when occupant's modifications are no longer adequate to serve their needs (Heidrich et al., 2017).

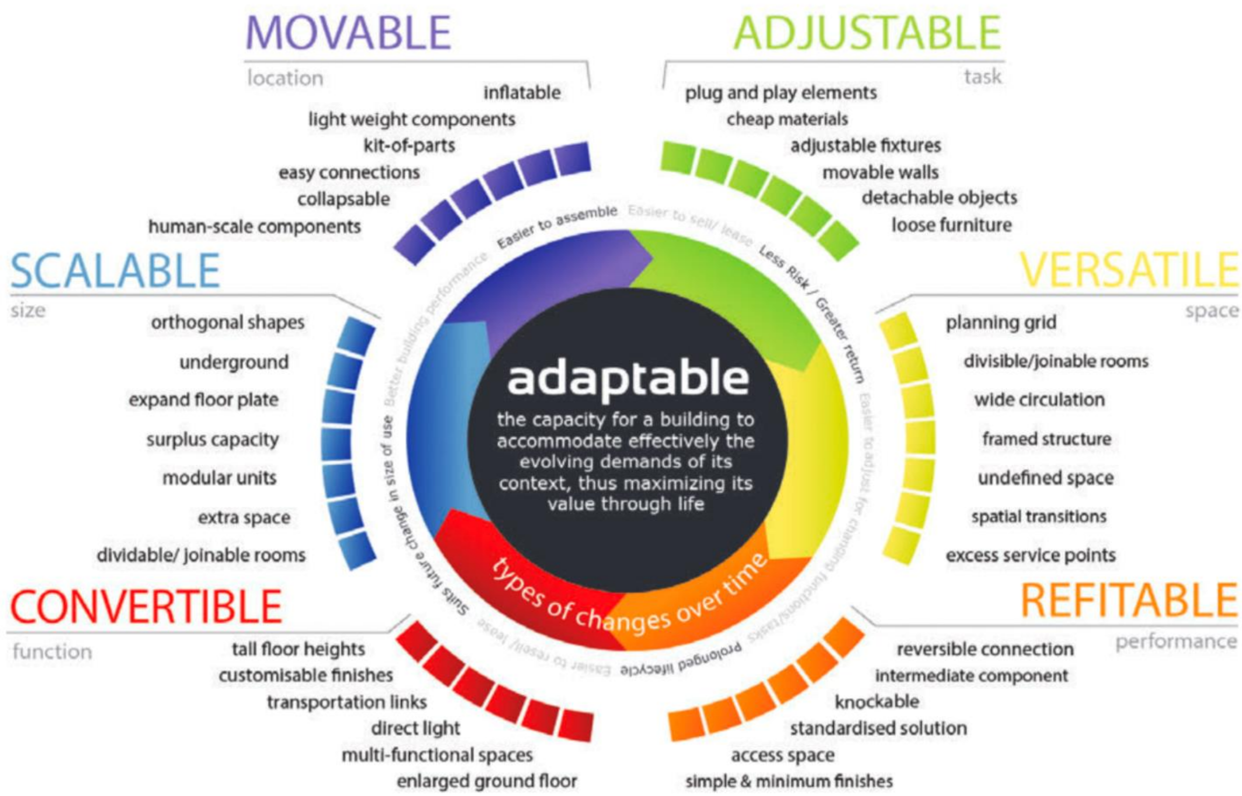


Figure 3 Frequency of changes in a building over time (adapted from Leman, 1962)

Adaptability indicators	Meaning	Example
Adjustable/ Generality	Change of tasks by users on a daily/monthly basis	Having a multi-purpose room, or a room ready to be used for multiple tasks with no/few adjustment. Possibility to divide spaces with movable walls.
Versatile (Flexible)	Change of space and location of services, furniture and equipment by users on a daily/monthly/basis	The possibility of moving furniture, equipment and even services where they need to be used.This and the previous are partially overlapping and related to frequent change of the building
Refit-able	Change of performance	Having the possibility of easily improving the performance of one or more components, without the need for replacing the entire system. E.G. installing a more efficient burner in a heat generator. This characteristic is very useful during retrofit and refurbishment.
Convertible	Change of function, space services	The possibility of changing the function of a building (or of a zone/space) without much effort and modification. E.g From an office to a residential unit or vice versa. This change is less frequent than Than the first two but nevertheless very important.
Scalable/Elastic	Change of size of building	Being able to increase/decrease surfaces and volumes of the building without big effort and using modular components. This is relevant e.g. For factories with expansion plans.
Movable	Change of location of fabric	Being able to move the entire building or a part of it without demolishing it, but dismantling and/ or reusing it.

Tableau 2: Indicators of adaptability, Adapted from (Heidrich et al., 2017)

The types of changes are positioned in a space-time continuum (Schmidt III, R., & Austin, S., 2016), as presented on Figure 4.

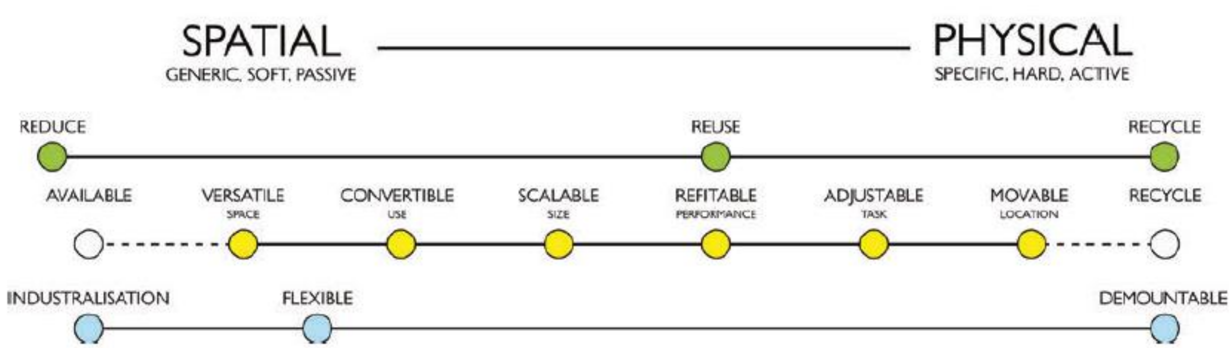


Figure 4 Adaptability types of models, (Schmidt III & Austin, 2016)

The six types of adaptability can be organized along a spatial–physical spectrum that coincides with the 3Rs of sustainability. The spatial types versatile and convertible were found to be much more prevalent than the physical types. In addition, spatial and physical types of adaptability behave differently: spatial types are spread throughout the building layers, while physical types are more concentrated in one or two building layers. The spectrum of adaptability types can be broadened to pre-use and post-use phases which is indicated by the white circles. This broader spectrum coincides with the Industrialisation-Flexible-Demountable (IFD) approach (blue circles) discussed briefly by the authors.

3.2.2. Design strategies and building characteristics

Based on the relationships and combinations between the building (shearing) layers, on the Adaptability types (Core Concept Model of adaptability) and taking into consideration the spatial and physical elements of a building, (Schmidt III & Austin, 2016a) define Design Strategies and Building characteristics Figure 5.

PHYSICAL	
DSI: MODULARITY	
CARI	Reversible
CAR2	Movable stuff
CAR3	Component accessibility
CAR4	Functional separation
DS2: DESIGN 'IN' TIME	
CAR5	Service zones
CAR6	Configurable stuff
CAR7	Multi-functional components
CAR8	Not precious
CAR9	'Extra' components
DS3: LONG LIFE	
CAR10	Durability
CAR11	Mature component
CAR12	Efficient services
CAR13	Good craftmenship
CAR14	Overdesign capacity
CAR15	Readily available materials
DS4: SIMPLICITY & LEGIBILITY	
CAR16	Standardised components
CAR17	Standard component locations
CAR18	Off-site construction
CAR19	Simple construction method

SPATIAL	
DS5: LOOSE FIT	
CAR20	Open space
CAR21	Support space
CAR22	Oversize space
DS6: SPATIAL PLANNING	
CAR23	Typology pattern
CAR24	Joinable/divisble space
CAR25	Modular coordination
CAR26	Connect buildings
CAR27	Standard room size(s)
CAR28	Spatial variety
CAR29	Spatial ambiguity
CAR30	Spatial zones
CAR31	Spatial proximity
CAR32	Simple plan
CAR33	Standard grid
CAR34	Simple form
DS7: PASSIVE TECHNIQUES	
CAR35	Multiple ventilation strategies
CAR36	Shallow plan depth
CAR37	Passive climate control
CAR38	Building orientation
CAR39	Good daylighting
DS8: UNFINISHED DESIGN	
CAR40	Space to grow into
CAR41	Phased
CAR42	User customisation
DS9: MAXIMISE BUILDING USE	
CAR43	Multi-functional spaces
CAR44	Use differentiation
CAR45	Mixed demographics
CAR46	Multiple/mixed tenure
CAR47	Shared ownership
CAR48	Isolatable
CAR49	Multiple access points
DS9: INCREASE INTERACTIVITY	
CAR50	Physical linkage
CAR51	Visual linkage

SCALES	
DS11: AESTHETICS	
CAR52	Attitude & character
CAR53	Spatial quality
CAR54	Building image
CAR55	Quirkiness
CAR56	Time interwoven
DS12: MULTIPLE SCALES	
CAR57	Good location
CAR58	Contextual
CAR59	Circulation (neighbourhood scale)
CAR60	A communal place

ADAPTABILITY TYPES

AT1	Adjustable
AT2	Versatile
AT3	Refitable
AT4	Convertible
AT5	Scalable
AT6	Movable

BUILDING LAYERS

L1	Social
L2	Space
L3	Stuff
L4	Space plan
LS	Services
L6	Skin
L7	Structure
L8	Site
L9	Surroundings

DESIGN RESOURCES

DR1	Design guidelines
DR2	Critical parameters
DR3	Scenario planning
DR4	Films
DR5	'Active' drawings
DR6	Benefit mapping
DR7	Evaluation tools
DR8	Organogram
DR9	Project precedents
DR10	Parti diagram
DR11	Workshop
DR12	Website

CONTEXTUAL CONTINGENCIES

STAKEHOLDERS	
CON1	Client mindset
CON2	Architect mindset
CON3	End-users
CON4	Other stakeholders
CON5	Culture
RULES	
CON6	Building regulations
CON7	Taxation
CON8	Heritage protection
CON9	Planning regulations
CON10	Industry standards

PHASES	
CON11	Fragmented process
CON12	Brief(ing)
CON13	Procurement route
CON14	Good management
CON15	Occupation
ECONOMICS	
CON16	Business models
CON17	Valuation practices
CON18	Market forces
CON19	Funding methods
CON20	Risk

MODELS

M1	Design perspectives
M2	Time and context
M3	Harmonising approaches
M4	Building layers
M5	DSM
M6	Adaptability types
M7	DfA
M8	Fragmentation
M9	Building specification
M10	Value equations
M11	Benefit mapping
M12	Critical decision
M13	Funding method
M14	Linking
M15	Framecycle
M16	Sources
M17	Design process
M18	Causal links
M19	Cost certainty
M20	Pathways

Figure 5 Design strategies & building characteristics (Schmidt III & Austin, 2016)

3.2.3. Framework for adaptable architecture and Rhythmic Buildings

By analyzing the previous theories aiming at adaptable architecture, some gaps are identified, namely: lack of specified strategies to address all three main pillars of sustainability - economic, social and environmental (van Ellen, Bridgens, Burford, & Heidrich, 2021). Adaptable buildings can contribute to all aspects of sustainability. To address this gap, van Ellen et al., (2021) proposed the 'Rhythmic Buildings', framework which is divided into three polygons to illustrate the three pillars of sustainability Figure 6 . The various Adaptability strategies (small white circles on the figure) are classified (and this way characterized) by their position in the three polygons. The faces of the polygons show the different aspects of change in the context of the specified pillar, and the three polygons overlap together. So, it is obvious that these aspects are interrelated and influence each other.

The environment polygon highlights (on the 4 exterior segments) the environment contribution criteria: microclimate (indoor climate of the building and space around the indoor space climate and it's identified by thermo physical properties), urban climate (has a high influence on comfort and wellbeing of dwellers, especially on toxicity which is emerging from the infrastructure and consummation hubs), local climate (which is related to the rotation of the earth around the sun and the rate of getting benefit from the sunlight during different hours a day and four seasons a year), and climate change (include the parameters of energy emissions and follow the global targets).

The economy polygon addresses the economic aspects and the related contextual aspects are defined as follows: schedule (related to the behaviour of the users and activities related to the function of buildings), function (the function of the building is the most important parameter, over time building needs the ability to provide the possibility for users to change the function if they need), industrial ecology model (includes the metabolism and resources parameters), economy (concentrates on politics, legislations and growth), industrial economy (involves resources and metabolism parameters) (van Ellen et al., 2021).

The society polygon, similarly, to the two other polygons, addresses the changing needs of users in the built environment. It is influenced by changes in physiology (safety, love, belongings, and esteem), comfort (humidity, noise, daylight levels, and temperature are some of its criteria), and behaviour. According to the authors, in the built environment, there are two kinds of behavioural influence: the first is a behavioural adaptation, which is how the body adapts to extreme weather conditions and is covered in the physiology section; the second type concerns how our conscious behaviour affects our level of comfort (van Ellen et al., 2021).

The Rhythmic Building framework tries to address some gaps in the previous models and achieve a more comprehensive model by supporting society, environment, and economic aspects in the context of design for adaptability. Indeed, this model can guide designers towards a more holistic approach to adaptable building.

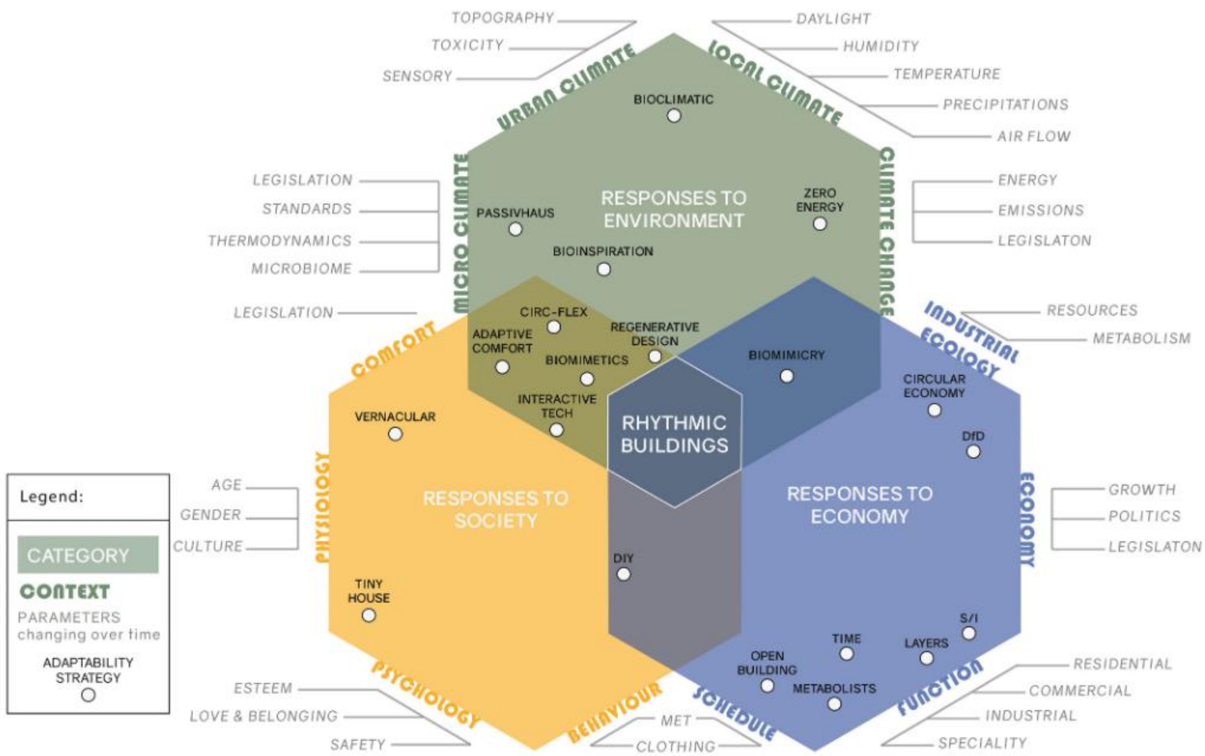


Figure 6 Framework for adaptable architecture including a wider context. Source:(van Ellen et al., 2021)

Comparing three prominent theories in the context of adaptable buildings and circular economy – the Core Concept Model of Adaptability, and the Model from Design Strategies & Building Characteristics by Schmidt III & Austin (2016) and the framework for adaptable architecture and rhythmic model, reveals distinct approaches and focuses within this field.

1. Core Concept Model of Adaptability: This model emphasizes the inherent flexibility in the design and structure of buildings. It advocates for a design approach that allows for easy modification and reconfiguration to meet changing needs over time. This aligns well with the principles of the circular economy by reducing the need for new construction, thus conserving resources and minimizing waste.

2. Design Strategies & Building Characteristics: This model introduces a unique perspective by focusing on the rhythmic changes in building usage and occupancy patterns. It suggests design strategies that accommodate these fluctuations, thereby enhancing the building's functional lifespan. This concept dovetails with circular economy objectives by advocating for buildings that can continuously adapt and evolve, thereby extending their usability and reducing the need for new resources.
3. This model emphasizes a strategic approach to building design that incorporates adaptability as a key characteristic. It advocates for incorporating features that allow buildings to evolve over time in response to changing user needs and environmental conditions. This approach is highly relevant to the circular economy as it emphasizes the efficient use of resources and the reduction of waste through the prolonged usability and adaptability of buildings.

3.3. Evaluation methods for the adaptability of a building

This section will address, firstly, evaluation methods for assessing the adaptability of new building designs and, on a second place, frameworks for existing buildings evaluation. Some of the evaluation criteria are common for the two contexts (existing and new buildings) and are present in both. Also, once a decision is made for an existing building to be reused, adaptability principles for a new design can be applied. The last framework presented in this chapter addresses Circular Economy in Construction and is only partially applicable for adaptability evaluation.

3.3.1. Spatial Assessment of Generality and Adaptability (SAGA) method

This model identifies the possibility of changes in building spaces (plans) and then evaluates the generality (passive support for a change) and adaptability (active support for a change) of the building's spatial configuration (Herthogs, Debacker, Tunçer, De Weerdt, & De Temmerman, 2019) through five indicators. The generality and adaptability of a floor plan can be expressed in terms of graph permeability using a set of five quantitative indicators. To illustrate this method, the authors evaluate six representative plan layouts and discuss how their generality and adaptability scores relate to their spatial configuration Figure **7** .The SAGA method targets two areas of application. First, SAGA's global graph indicators can be used to analyze and compare large sets of plan graphs, for example, to map or plan adaptable capacity throughout a building or city. Second, the SAGA method can serve as a tool to inform design, allowing architects to improve the generality and adaptability of their plan layouts. While the authors conclude that the method has significant strengths and promising applications, the paper ends by discussing ways to make the assessment more robust and extend it beyond measuring spatial configuration (Herthogs et al., 2019).

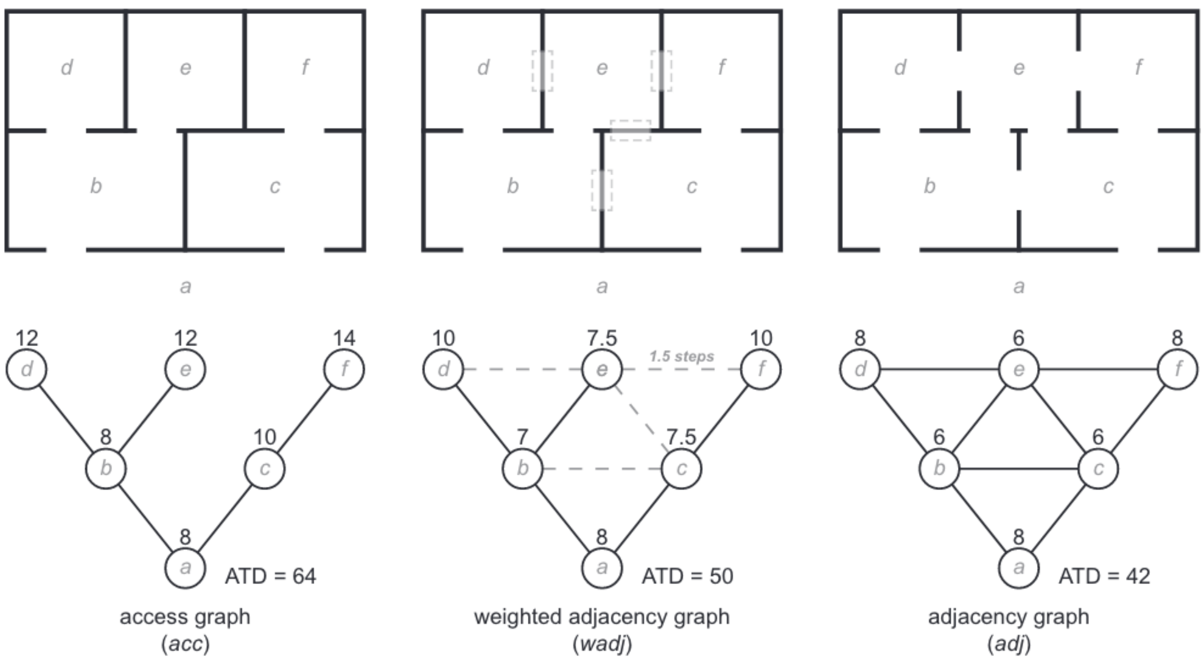


Figure 7: The SAGA method uses three related plan graphs to determine Generality, Adaptability, and Maximum Adaptability, which are proportional to the permeability of their respective plan graphs. Permeability can be expressed as the inverse of Aggregated Total.

The primary premise of the SAGA technique is that the permeability of an existing plan layout is a reflection of its Generality (G), with permeability stated as a direct opposite of the related plan graph's Aggregated Total Depth (ATD). Because generality is a feature of an existing facility, the ATD is estimated using the plan layout's access graph (acc), which is a plan graph with edges representing physical connections across space Équation **1**

Équation 1

$$G \sim \frac{1}{ATD_{acc}}$$

As illustrated in Figure **7** the plan graph permeability shows that by increasing the number of openings, the potential of buildings for changes increases and modification will be easier in future. The evaluation method of SAGA method shows the level of generality of a space plan which depends on the number of possible combinations of spaces permitted.

This model does not take in consideration the importance of connections between some functions of spaces in the building, nor some service barriers. For example, a particular arrangement of pipes and wires might not allow engineers to design a kitchen or bathroom wherever they want and count it as an option just because there are openings (Herthogs et al., 2019).

Evaluation methods for the potential for adaptability of existing building

More frameworks have been developed for the evaluation of the adaptability potential of existing buildings. This certainly reflects the fact that, nowadays, a larger proportion of construction projects are renovations of existing buildings.

3.3.2. Icon CUR framework

This conceptual framework is created with the objective to assist decision-makers in evaluating the current adaptability performance of a building in order to make better decisions about built assets at an early stage in the process, with the objective to identify which course of action to pursue (Langston & Smith, 2012). The resulting model, known as IconCUR, uses a weighted matrix methodology to obtain performance scores for condition, utilization and reward that are capable of mapping property decisions in 3-dimensional spaces over time.

It is used to present the current adaptability performance of a building. This model has X, Y and Z planes which are respectively related to the condition, use and rewards (**Erreur ! Source du renvoi introuvable.**). While the X and Y planes constitute the decision of the features suitable for the structure, the Z plane shows the power of this decision (Langston & Smith, 2012).

According to the location of the building in the 3D model ,alternative suggestions are presented in Tableau 3. The three axes (X, Y, Z) in the coordinate plane correspond to different definitions

Definition of axes in coordinate plane

x-axis : The design standard, maintained service level and regulatory compliance are scored for the building's structure, exterior envelope, interior finishes, engineering services and external works

y-axis : the demand and relevance; fitness for purpose and user satisfaction of the internal space, external space and outdoor site area; equipment and fit-out; and engineering systems are assessed

z-axis : reward, has two scores – one score for the collective utility which takes into account the economic performance and cultural, heritage and environmental values; the second score considers different stakeholders' interest/involvement in the short-, medium- and long-terms

Tableau 4.

According to the location of the building, as shown in Figure 8 , Figure 9, the IconCUR model suggests what action should be taken. Condition is scored from 1 (very low) to 5 (very high). The criterion 'condition' is defined as reflecting the physical characteristics of the property. In IconCUR, this is expressed in terms of three key attributes (design standard, maintained service level, and regulatory compliance). Design standard refers to the level of quality and includes issues such as durability and appearance. Maintained service level refers to the level of upkeep and includes issues such as regular repair and cleaning. The criterion 'utilization' is defined as reflecting the occupancy characteristics of the property. In IconCUR, this is expressed in terms of three key attributes (demand or relevance, fitness for purpose, and user satisfaction). Demand or relevance refer to the level of usage and include issues such as occupancy rates and capacity. Fitness for purpose refers to the level of suitability of the design to its functional objectives and includes issues such as flexibility and technology support. User satisfaction refers to the level of endorsement of the property and includes issues such as comfort and perceived utility (Benjamin, Christopher, & Carl, 2022)

Position	Suggestion
Low condition and low utilization	reconstruct or dispose
High condition and high utilization	retain or extend
Low condition and high utilization	renovate or preserve
High condition and low utilization	reuse or adapt

Tableau 3 : Position of the structure in the model

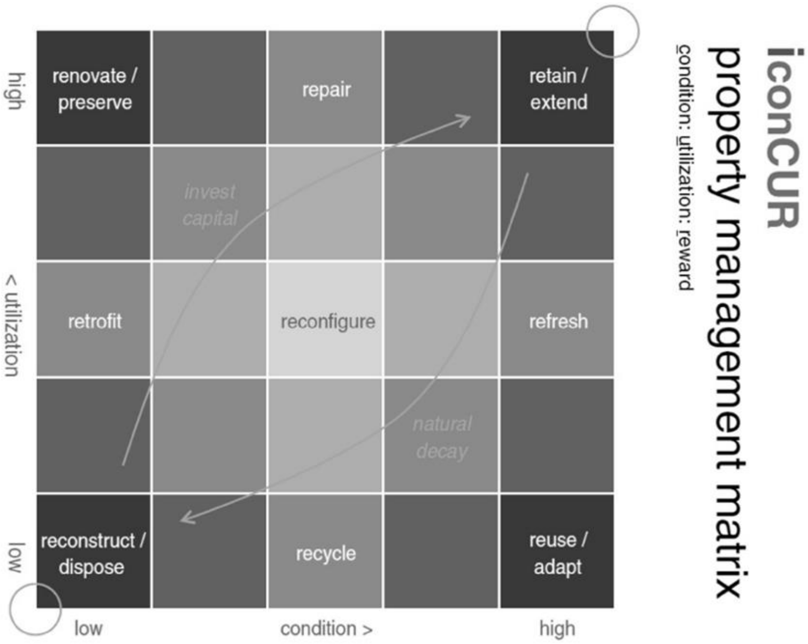


Figure 8 : The space frame of the IconCUR model, source:(Langston & Smith, 2012)

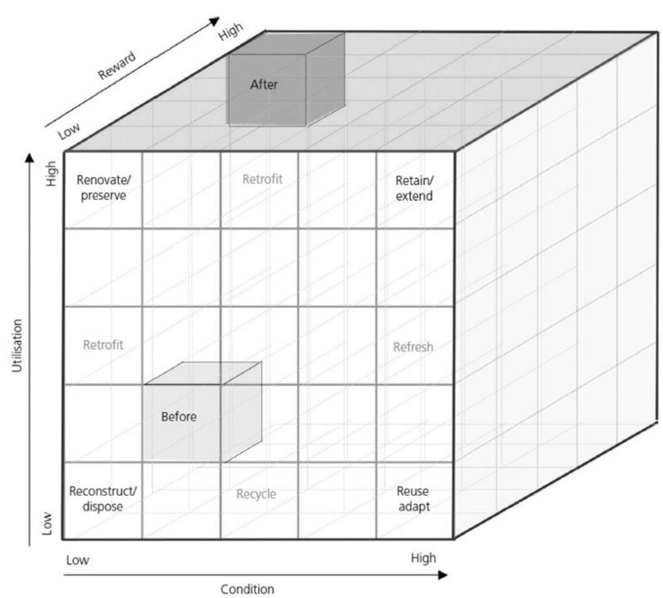


Figure 9 : Three-dimensional IconCUR - position of an asset before and after intervention, Source:(Unver, Alptekin, & Kalkan, 2022)

Definition of axes in coordinate plane
x-axis : The design standard, maintained service level and regulatory compliance are scored for the building's structure, exterior envelope, interior finishes, engineering services and external works
y-axis : the demand and relevance; fitness for purpose and user satisfaction of the internal space, external space and outdoor site area; equipment and fit-out; and engineering systems are assessed
z-axis : reward, has two scores – one score for the collective utility which takes into account the economic performance and cultural, heritage and environmental values; the second score considers different stakeholders' interest/involvement in the short-, medium- and long-terms

Tableau 4 : Definitions of axes in the coordinate plane

The IconCUR conceptual framework has the potential to assist decision-makers in evaluating the current adaptability performance of a building in order to make better informed decisions at an early stage of the process.

3.3.3. Circular Construction Evaluation Framework (CCEF)

The circular construction evaluation framework proposed by (Dams et al., 2021) provides clients, consultants, and contractors with an opportunity to evaluate the buildings. This framework evaluates the building in both whole buildings levels and building as an element level from the beginning of the building design and planning stage for new buildings or reuse of the existing building and the total score of adaptability in the whole level or element level shows the rate of adaptability in the building Figure 10 ,Tableau 5 describes the result of the adaptability evaluation in order to the total score.

In the CCEF, like in the AdaptSTAR and ARP evaluation frameworks, the main idea is the evaluation of different aspects of the buildings to increase their sustainability through circularity. The reuse of the building is one of the highest forms of sustainable building (Conejos, Langston, & Smith, 2014) and it is part of these three evaluation frameworks. While the AdaptSTAR focused on evaluating the historical buildings with seven categories (political, social, etc.) to find the appropriate and new function for them, the CCEF concentrates on the physical aspects of the building with the approach of designing the building for future disassembly and adaptability. At the whole building level the SSEF covers the potential of the building to be adapted including the designing and planning stage such as dimension, types of connections, ease of access and core concept framework indicators (convertibility, versatility, expandability, etc.) (Adams, Osmani, Thorpe, & Thornback, 2017).

As mentioned previously, CCEF is developed in two sections, the upper one deals with the overall construction: a lower rate denotes less circularity and the higher rate denotes a high level of circularity and adaptation in design, material, construction, etc. At the element level, CCEF is developed to evaluate and record the history, current status and future possibilities and abilities of the buildings. At the whole building level, CCEF covers the abilities of the building to be adapted from primary stages, design and planning stages.

Finally, some adaptability models are intended to be applied to existing buildings, but frameworks can also be aimed at the early stages of design. (Langston & Shen, 2007) developed the Adaptive Reuse Potential (ARP) model, which depicts a useful life period as a fraction of the full design life a building is structurally capable of providing as a descending curve graph. (Conejos et al., 2014) published the Adaptstar method, which assigns a star rating to a specific project; although data sets were limited, Adaptstar demonstrated that buildings with higher adaptability had longer useful lives and took longer to become obsolete when used in conjunction with the ARP model (Dams et al., 2021). CCEF is created for engineers, designers, contractors and especially clients who wish to consider and execute sustainable ratios by giving transparent data by this method to assess the adaptability and circularity of a project in early design and planning stages with the goal of guiding and informing decision makers and finally increasing sustainability of buildings (Dams et al., 2021).

Score/ 5	%	Whole building level indicators
Zero	less than 10%	A 'No' answer; no disassembly plan or sequence; No scope for converting, adapting or expanding; highly complex or bespoke design with sequential construction required; non-reversible connections; monolithic construction; no accessibility or disassembly without significant damage to surrounding materials; Very high use of synthetic chemicals, resins, finishes and treatments.
One	10%–29%	Minimal consideration for disassembly in design and plans; Minimal scope for converting, adapting or expanding; complex design with varying elements requiring sequential construction; limited accessibility or scope for disassembly without significant damage to surrounding materials; high use of synthetic chemicals, resins, finishes and treatments.
Two	30%–49%	Some consideration for disassembly; Some scope for converting, adapting or expanding; moderately complex design with variability in parts and sequential construction required; limited accessibility or scope for disassembly without some damage to surrounding materials; significant use of synthetic chemicals, resins, finishes and treatments.
Three	50%–69%	Moderately detailed and clear disassembly plans; scope for modest adaptation or expansion; some simplicity in design, moderate variability in elements, some parallel construction possible; reasonably accessible, scope for disassembly with minor damage to surrounding materials; moderate use of synthetic chemicals, resins, finishes and treatments.
Four	70%–89%	Reasonably comprehensive disassembly plan and sequence; scope for adaptation and/or expansion; simplicity and/or standardisation in design, moderate component variation; parallel construction possible; mostly accessible, disassembly possible with only very minor damage to surrounding materials; little use of synthetic chemicals, resins, finishes and treatments.
Five	90% or higher	A 'Yes' answer; Comprehensive, clear disassembly plan and sequence prepared during design stage with clear specifications; Extensive scope for adaptation and/or significant expansion without significant modification to foundations; simplicity, standardisation and modularity in design with minimal variation in components; independent, parallel construction entirely possible; reversible connections; full accessibility with minimal work and scope for full disassembly with no damage to surrounding materials; No synthetic chemicals, resins, finishes or treatments.

Tableau 5 Indications of numerical scores from zero to five within the CCEF - whole building level. Source: (Dams et al., 2021)

Score/ 5	%	Element level indicators
Zero	less than 10%	A 'No' answer; no reuse or recycling of elements at the end of the first design life; No material inventory, no recorded details of elements; virgin materials; missing or incomplete life cycle analysis (LCA), no environmental product declaration (EPD); materials may be durable but there is no scope for reuse or recycling within construction, therefore significant downgrading, landfill or incineration will take place at the end of the first design life; No expansion without significant and expensive modification to foundations..
One	10%–29%	Very little reuse or recycling of elements at the end of design life; minimal material information, minimal reclaimed or recycled material; largely incomplete LCA, no EPD; materials may be durable but very little scope for reuse or recycling, downgrading, landfill or incineration expected at the end of the first design life.
Two	30%–49%	Little reuse or recycling of elements at the end of design life; little material information, little reclaimed or recycled material; partially incomplete LCA, no EPD; materials may be durable but minimal scope for reuse or recycling with potential requirement for landfill or incineration; limited scope for additional design lives; minimal use of sustainably sourced materials.
Three	50%–69%	Some reuse or recycling of elements at the end of design life; basic material information, some reclaimed or recycled material; partially incomplete LCA, possible EPD; reasonably durable materials with scope for reuse or recycling; scope for a second design life; sustainably sourced materials.
Four	70%–89%	Considerable reuse or recycling of elements at the end of design life; material inventory, significant use of reclaimed or recycled material; complete LCA with end-of-life scenario, complete EPD available; long design life with durable, reusable materials; scope for subsequent design lives; sustainably sourced materials.
Five	90% or higher	A 'Yes' answer; full reuse or recycling of elements at the end of design life; comprehensive material inventory stating content and origin, extensive use of reclaimed or recycled materials; complete LCA with end-of-life scenarios, extensive EPD available; long design life with durable, reusable materials; scope for multiple design lives; sustainably sourced materials.

Tableau 6 Indications of numerical scores from zero to five within the CCEF - whole building level. Source: (Dams et al., 2021)

WHOLE BUILDING LEVEL	Recorded information: design, data, materials			Adaptability in design				Simplicity in design					Health and safety					
	Disassembly plan included in design drawings and specifications	Disassembly sequencing information	Clarity and transferability of plans and specifications	Versatility (in regular use, cosmetic change)	Convertability (partition/ space changes)	Expandability (vertical, without major foundation modification)	Expandability (horizontal, compatible foundations)	Parts per element	Standardisation and modularity of elements			Degree of element independence and classification of construction	Toxicity / synthetic chemicals	Ease of access, construction and disassembly				
									Dimensions	Component variation	Connections							
	0 (no plan) - 5 (Comprehensive, detailed, easy to follow plan)	0 (no) - 5 (Full, easy to follow sequence)	0 (incomplete or unclear) - 5 (full and clear)	% usuable space	% usuable space	% extra floorspace possible	% additional area available	0 (>5 parts), 1 (5 parts) - 5 (one part)	0 (high variability, bespoke) - 5 (high uniformity, modular)			0 (low- sequential, hierarchical) - 5 (high - independent, parallel)	0 (high toxicity) - 5 (Non-toxic)	0 (inaccessible) - 5 (Accessible)				
Sample Building																		
		Section total /15				Section total /20					Section total/ 25		Section total /10					
		Section total (%)				Section total (%)					Section total (%)		Section total (%)		Overall total /70		Overall total (%)	

ELEMENT / COMPONENT LEVEL	Circularity credentials of element/ component																	
	Durability			Material Inventory						Finishes/ treatments		Reversiblility of connections	Reusable (without restoration or modification)	Recyclable (No downgrading)				
	Number of previous design lives / uses	Length of previous design lives	Predicted length of current design life	Suppliers and production	Warranties	Donor Building(s)	Reclaimed and/or recycled content	Did reuse involve cleaning or restoration work?	Life Cycle Analysis with end of life scenario and Environmental product declaration	Synthetic/ chemical/ wet resins/ adhesives?	Chemical coatings							
	0 (virgin material) - 5 (five previous uses)	0 (zero), 1 (ten years)...5 (50+ years)		0 (no information) - 5 (full production and supplier information, including location; details of warranties and element history including donor building information)			% of element	0 (yes, extensive or N/A) - 5 (no, none)	0 (no information or EPD) - 5 (full LCA with origin of material, end-of-life scenario and EPD)	Yes (score 0), No (score 5)		1 (Cannot be reversed) - 5 (easily reversed)	% of element which can be reused	% of element which can be recycled				
Sample Element 1															Element 1 total /70		Element 1 (%)	
Sample Element 2															Element 2 total /70		Element 2 (%)	
Sample Element 3															Element 3 total /70		Element 3 (%)	
Sample Element 4															Element 4 total /70		Element 4 (%)	
Sample Element 5															Element 5 total /70		Element 5 (%)	
Sample Element 6															Element 6 total /70		Element 6 (%)	
															Element mean /70		Overall %	

Figure 10 Circular construction evaluation framework, showing evaluation criteria at both whole building and element/component levels. Source: (Dams et al., 2021)

4. Résultats

4.1. Entrevues

4.1.1. Introduction

La notion de l'économie circulaire est de plus en plus répandue de nos jours. L'adaptabilité est parmi les solutions qui peuvent atteindre certains objectifs de la circularité. Avec un potentiel important, la conception adaptable pourrait permettre de prolonger la durée de vie des composantes d'un bâtiment.

L'objectif de ce sondage est de collecter les différents facteurs de la conception adaptable. Bien au-delà des données recueillies de la revue de la littérature, il s'agit aussi d'identifier certaines pratiques dans un contexte local visant à atteindre la circularité.

Il comporte les résultats de 16 entrevues ainsi que :

- Les objectifs principaux des entrevues.
- La représentation des résultats de toutes les entrevues.
- L'analyse et l'interprétation des résultats.
- Des cas d'études réels pertinents cités par les participants.

4.1.2. Objectifs des entrevues

Ces entrevues ont pour objectifs :

- Collecte des facteurs de la conception adaptable.
- Identification des types de bâtiments à considérer et les types de changement nécessaires pour promouvoir l'adaptabilité dans le contexte local.
- Recadrement des critères d'évaluation identifiés dans la littérature par rapport au contexte local.
- Identification des stratégies de l'économie circulaire les plus efficaces du point de vue de l'adaptabilité.

4.1.3. Étapes de réalisation

Les entrevues ont été menées par une étudiante au doctorat à l'École de Technologie Supérieure, selon huit étapes. Elles sont décrites dans ce qui suit :

Étape 01 : Identification des participants

La première étape consistait à identifier l'échantillon des entrevues. Une liste de participants était dressée afin de les solliciter pour une entrevue de 45 minutes en moyenne.

Étape 02 : Préparation des questions de l'entrevue

Parallèlement à la première étape, la préparation des questions de l'entrevue était entamée. La liste de questions a été montée dans le but d'atteindre les objectifs de ce travail et d'enrichir le projet de recherche en question. Plusieurs itérations ont été faites pour aboutir à une entrevue organisée en cinq parties principales, chacune comportant des questions, à choix multiples ainsi que des questions ouvertes. Une présentation PowerPoint a été préparée pour faciliter la communication avec les participants.

Étape 03 : Sollicitation des participants par courriel

Une fois la liste des participant dressée et les questions prêtes, les personnes ont été contactées pour convenir une date de la rencontre virtuelle. Seize personnes ont accepté de participer à nos entrevues.

Étape 04 : Planification des rencontres en ligne

Les dates des entrevues ont été déterminées selon la convenance des participants. La durée moyenne de chacune était d'environ 45 minutes et les rencontres se sont tenues de façon virtuelle, sur Teams.

Étape 05 : Représentation des données recueillies des entrevues

Les données brutes ont été recueillies à partir des transcriptions des entrevues. Ces données sont présentées dans un fichier Excel avec les questions correspondantes. Les informations sont triées pour garder ce qui est essentiel. Il s'agit tout d'abord de supprimer les expressions en surplus. Ensuite, de ne garder que les mots clés, dans le même contexte. Les exemples et les explications sont traités à part. Finalement, pour procéder à la représentation graphique, un calcul des fréquences a été établi pour les questions à choix multiples. Chacune des questions ouvertes a été traitée individuellement. La représentation graphique a été réalisée en utilisant le logiciel Scimago, un outil sans code qui permet de créer des visualisations complexes à partir de de simples interactions de type "glisser-déposer" (Hassan-Montero, De-Moya-Anegón, & Guerrero-Bote, 2022).

Étape 06 : Analyse des résultats des entrevues

A cette étape, toutes les données recueillies lors des entrevues sont représentées graphiquement dans un rapport. Une analyse des résultats est faite pour en tirer des conclusions.

Étape 07 : Rédaction d'un rapport pour le CERIEC

Les résultats finaux des entrevues sont décrits dans le présent document. Ce rapport fait parties des livrables finaux de la solution #6 des projets du CERIEC en collaboration avec l'ÉTS.

Étape 08 : Communication des résultats par article de conférence

Ce travail fera l'objet d'une publication scientifique. Il porte sur les pratiques de l'industrie de la construction au Québec en termes d'adaptabilité.

4.1.4. Exemples pertinents

Les participants ont cité plusieurs exemples pertinents dans le contexte local. Les descriptions de chaque projet est présentée à part.

Le siège social de la SQI à Montréal

Un bâtiment d'environ 150 ans avec des bureaux administratifs. Le système de construction choisi a facilité l'adaptation en ayant des planchers surélevés. Ce choix a permis de déplacer facilement les murs et refaire des pièces sans avoir à faire d'autres modifications. Ce système permet aussi de faciliter la mécanique du bâtiment et d'économiser les matériaux. Néanmoins, la difficulté est la modification de l'enveloppe extérieure, y compris les fenêtres et les portes par exemple, ce qui présente certaines restrictions.

Agrandissement d'hôpitaux pour la Covid-19

Dans le contexte pandémique Covid-19, des agrandissements d'hôpitaux ont été faits en bâtissant des annexes temporaires dans un système modulaire à enlever après 7 ans. L'espace sera relocalisé et réutilisé pour le stationnement. Ces agrandissements nécessitent des couts élevés et beaucoup de logistique. La difficulté réside non seulement dans la structure et le site mais aussi dans la logistique qui est compliquée.

Habitations de l'ancien site des sœurs Sainte-Anne

Les habitations de l'ancien site des sœurs Sainte-Anne représentent des anciennes chambres auparavant. Ces dernières n'étaient pas en normes, d'où le premier défi d'avoir toutes les commodités. Adapter la ventilation, la lumière et toute la mécanique est difficile, et l'isolation des murs l'est encore plus. Dans ce cas, cette remise aux normes et les règlements qui ont évolué posent plusieurs difficultés.

Parking 4 à l'aéroport de Montréal

Le stationnement 4 à l'aéroport de Montréal est un parking de 4 étages. La demande a été faite pour la planification sur 60 ans, dont les 20 premières années pour le stationnement et la suite en les réadaptant en bâtiment bureau.

Étude pour la conservation de la ville - Calgary

Une étude a été faite pour la ville de Calgary pour la conservation du patrimoine en limitant les impacts environnementaux. Des analyses de cycle de vie ont été faites pour argumenter les choix en plus des performances énergétiques. La difficulté étant d'atteindre les objectifs prédéfinis en conservant les bâtiments existants pour répondre aux exigences patrimoniales.

CHUM de Montréal

Pour cet hôpital, il y a des équipements qui ont beaucoup évolué à travers le temps. Cette évolution rapide complique le processus d'adaptabilité dans le sens où il est difficile de prédire les technologies du future et leurs évolutions.

Bibliothèque – Gaston Miron

Sachant que les besoins de la ville évoluent à travers le temps, la bibliothèque située à l'édifice Gaston Miron en face du Parc de Lafontaine a été conçue pour une durée de vie de 150 ans, mais la SQI a décidé de déposer tous ses livres à la grande bibliothèque de Montréal, de ce fait, le bâtiment était vacant et il fallait lui trouver une nouvelle fonction. Cette flexibilité mène à des espaces polyvalents et multifonctions difficiles à concevoir.

Projet à Blain ville

Les employés d'un bâtiment qui va fermer doivent être affectés dans deux autres bâtiments, qui, actuellement, ne peuvent pas tous les accueillir. Les raisons de la rénovation sont d'abord d'accueillir cette masse d'employés puis aussi de les adapter aux besoins actuels. Cette adaptation des anciens bâtiments devrait prendre en compte aussi les besoins du future pour s'adapter aux changements.

4.2. Résultats des entrevues

L'entrevue comporte cinq parties. La première concerne la présentation de l'interlocuteur. La deuxième partie revient sur l'expérience professionnelle de chaque participant. La troisième partie porte sur la circularité alors que la quatrième se concentre sur l'adaptabilité. Enfin, la dernière partie regroupe des questions sur les attentes et les exigences des clients et du gouvernement.

4.2.1. Partie 01 : Présentation de l'interlocuteur

Dans cette première partie de l'interview, nous avons posé trois questions. Tout d'abord, après la présentation de l'interlocuteur, une question porte sur sa profession. Ensuite, une autre sur les différents rôles du participant au sein de l'organisme. Finalement, une dernière question sur les responsabilités qui lui sont assignées.

Les résultats de cette partie sont présentés comme suit :

Profession des participants

Dans ces entrevues, seize participants ont répondu aux questions. Le

Tableau **7** regroupe les professions des participants. De même, une représentation graphique des fréquences de chaque profession par rapport à l'échantillon total est présentée dans la Figure 11 ci-après.

Profession	Nombre de participants
Architecte	5
Ingénieur	4
Directeur général	2
Designer d'intérieur	1
Associé stratégie durable	1
Associé directeur	1
Conseiller	1
Présidente des gestions immobilières	1
Total	**16**

Tableau 7. Profession des participants interrogés

En analysant ces résultats, la plus grande majorité des participants sont des architectes de formation, environ 31%. Tandis que 25% des participants sont des ingénieurs et 13% des directeurs généraux. Finalement, un pourcentage similaire pour les autres professions : Designer d'intérieur, associé stratégie durable, associé directeur, conseiller et présidente des gestions immobilières.

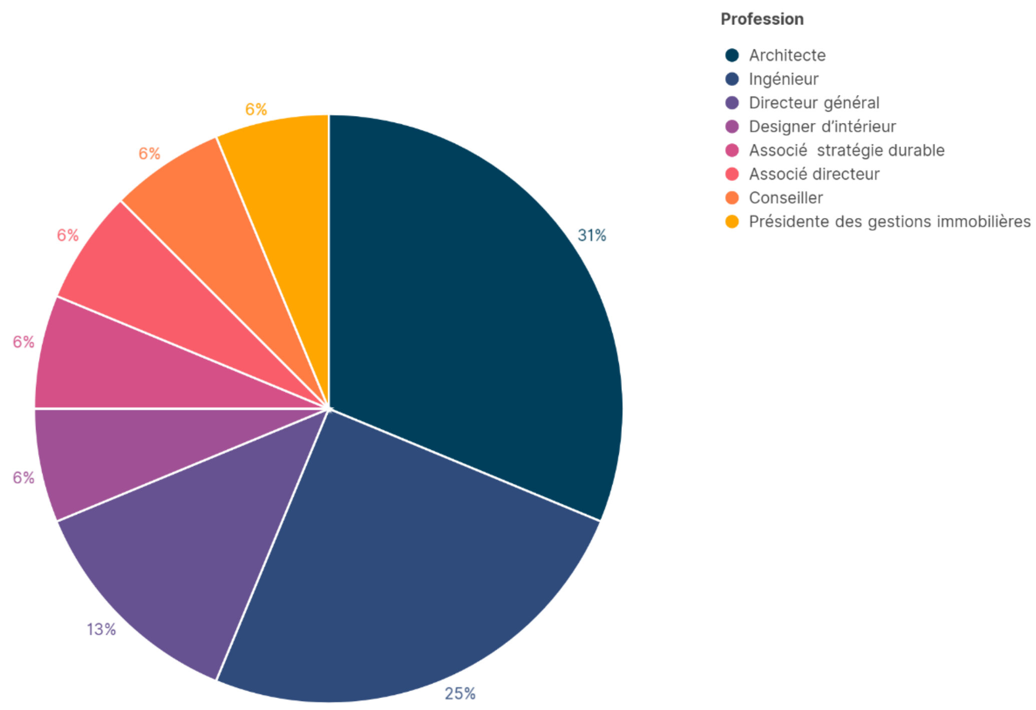


Figure 11 Représentation graphique de la fréquence des professions des participants.

Afin de mieux catégoriser les différentes professions selon les types d'organismes, le

Tableau 8 regroupe le nombre des participants dans chaque organisme. Dans l'échantillon choisi, cinq participants sont liés à des firmes d'architecture, quatre autres travaillent dans des organismes de donneurs d'ouvrages publics. Les autres catégories s'agissent d'entrepreneurs généraux, d'associations, d'organismes à but non lucratif ou de promotion immobilière.

Rôle	Type d'organisme	Organisme	Nombre
Firme ou cabinet d'architecture	Privé	Neuf Architectes Rose Architecture Lemay Coarchitecture Aédifica	5
	Public	SQI	6
		SHQ	

Donneur d'ouvrages		ÉTS	
	Public	Hydro Québec	
Entrepreneur général		Pomerleau	1
Association		ACQ	1
	Organisme à but non lucratif	Éco Bâtiment	1
	Public	Ville de Montréal	1
Promotion immobilière		Quo Vadis	1
Total		**16**	

Tableau 8. Types d'organismes ou travaillent les participants.

Rôles des participants

Le Tableau 9 est un récapitulatif des rôles des participants. Ils sont regroupés selon les types d'organismes où ils travaillent. Les rôles sont divers et nombreux, néanmoins, les participants ont cité les plus importants. Cependant, les responsabilités représentées dans la question suivante éclaircissent plus en détail les rôles décrits dans la présente partie.

Type d'organisme	Rôles des participants
Donneur d'ouvrage	- Conseillère dans une direction qui s'appelle la direction d'expertise bâti immobilière. - Accompagnement des différents acteurs qui jouent un rôle dans l'industrie de l'habitation. - Mise en œuvre de certaines politiques gouvernementales qui ont un lien avec l'environnement bâti. - Directeur général, de l'expertise technique et du développement durable. - Participer à tous les projets de développement immobilier. - Contribuer à tous les projets de développement immobilier. - La responsable de la direction de la normalisation et du développement durable - Gestion des projets pour la pérennité des bâtiments et des projets d'aménagement. - Accommoder les clients pour la stratégie immobilière.

Firme ou cabinet d'architecture	- En charge des pratiques émergentes dans le nouveau département de stratégie durable. - Vice-présidente ingénierie et développement durable. - Assister les projets de l'équipe stratégie durable : architecture, design intérieur, architecture du paysage et design urbain. - Diriger sa propre firme d'architecture. - Associé directeur gestion de personnel développement et de marché. - Spécialisée dans les planification, conception et réalisation d'environnement de travail.
Entrepreneur général	- Gérant innovation, recherche et développement
Association	- Conseillère en développement innovation.
Organisme à but non lucratif	- Directrice générale d'un organisme qui s'intéresse aux bâtiments durables en travaillant sur l'efficacité énergétique et la certification LEED.
Promotion immobilière	- Prendre la stratégie au sujet de nos édifices en carboneutralité j'arrange le financement, je fais tout le travail au sujet des choix de matériel et je fais aussi le planning pour nos projets

Tableau 9. Récapitulatif des rôles des participants.

Responsabilités

La question suivante vise à cerner les responsabilités des participants. Afin de mieux les catégoriser, les réponses sont regroupées selon le type d'activité. Selon les informations obtenues, cinq catégories d'activités ont été établies : la gestion, l'exécution, la supervision, la recherche et le développement, et le marketing. Le

Tableau 10 est un récapitulatif des différentes responsabilités assumées par les participants cités. Ils sont catégorisés selon leurs professions respectives afin d'assurer l'anonymat des participants.

Activités	Responsabilités	Participants
Gestion	- Faire les études d'avant-projet dans le cadre de la réalisation des projets ainsi que l'analyse des différents scénarios possibles et les documents à utiliser - S'assurer d'atteindre les objectifs des projets internes et externes dans le volet de stratégie durable - S'occuper de la planification des projets de développement des résidences - Gestion de la planification immobilières - Piloter les appels d'offres	Ing-1, Asso-1, Dir-2, Arc-4, Ing-4, Arc-5. Prés-1

	- Préparer les documentations au sujet des certifications - Coordination des différentes activités pour le développement durable	
Exécution	- Supporter les différentes parties prenantes d'un projet dans divers volets - S'assurer que les projets répondent aux exigences	Con-1, Ing-4
Supervision	- Superviser les équipes de recherche et développement opérationnelle pour intégrer les nouvelles technologies - Donner les orientations en menant des projets initialement sur le patrimoine religieux pour le climat et en aidant à les requalifier - Accompagnement des projets pour la transition écologique - Superviser une équipe qui fait la gestion, qui fait aussi la construction de nouvelles propriétés	Ing-2, Ing-3, Dir-1, Arc-4, Asso-2, Prés-1
Recherche et développement	- En charge des questions de l'innovation et du développement durable en les intégrant dans les différents programmes et directives de construction. - Recherche sur les innovations et les nouveaux standards à mettre en application - En charge de tout ce qui est virage numérique des entreprises ainsi que tous les enjeux de la construction durable - Faire partie du conseil technique du Génie-Conseil sur le thème du bâtiment durable, des certifications et de contrôle qualité - Diriger les différents projets dans une pratique plus écologique et communautaires - Amener de nouvelles idées et de s'assurer que tous les projets sont en marche - Proposer les meilleurs scénarios possibles	Arc-2, Arc-1, Des-1, Ing-3, Arc-3, Asso-2, Con-1
Marketing	- Collection des données au sujet des cibles	Prés-1

Tableau 10. Récapitulatif des responsabilités des participants

4.2.2. Partie 02 : Expérience professionnelle

La partie 02 de l'entrevue a été effectuée dans le but de cerner l'expérience professionnelle des participants. Elle comporte cinq parties, pour mieux comprendre les types des projets sur lesquels travaillent les participants ainsi que leurs échelles. Les deux dernières questions portent sur l'application de l'adaptabilité. Les résultats sont les suivants pour chaque question.

Sur quels types de projets travaillez-vous ?

Plusieurs participants travaillent sur divers types de projets simultanément. Cependant, la majorité des participants travaillent sur des projets institutionnels, (environ 75%) ou résidentiels qui représentent 63%. Seulement 38% des participants travaillent sur des projets commerciaux. Les projets industriels et d'infrastructure sont en minorité (respectivement 25% et 13%). Les différentes proportions sont représentées dans la Figure 12.

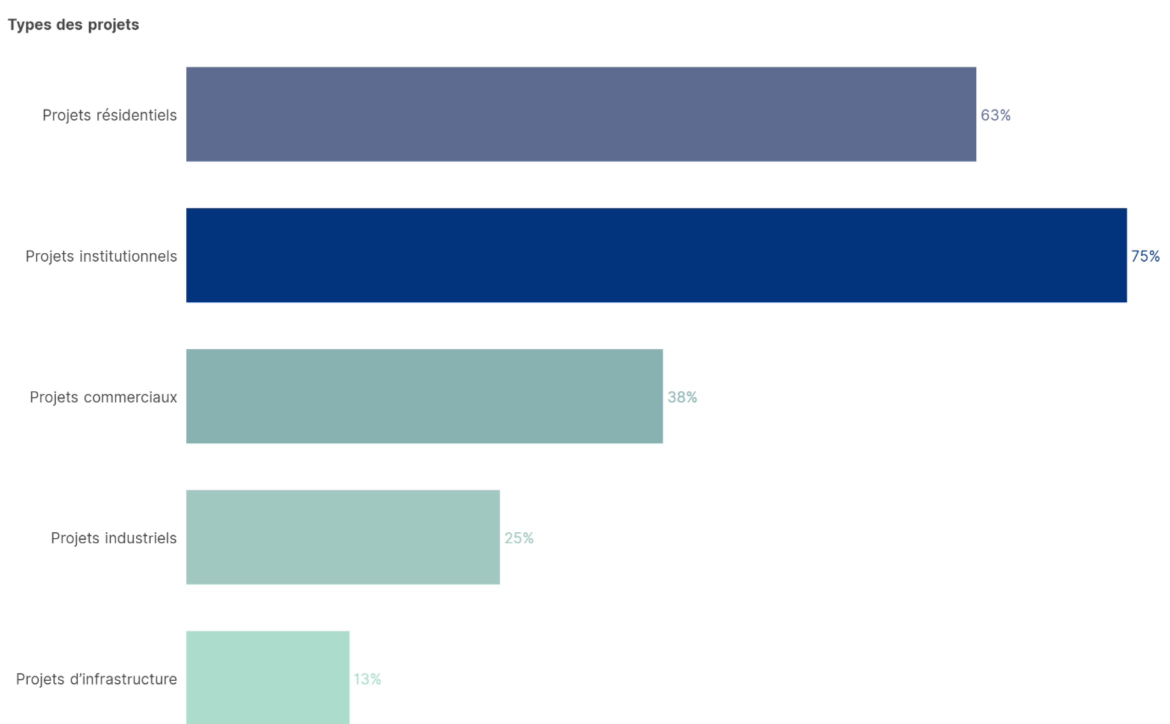


Figure 12. Types de projets sur lesquels travaillent les participants.

Sur quels types de projets travaillez-vous habituellement ?

Les participants ont été questionnés sur les types des projets sur lesquels ils travaillent : publics, privés ou semi-privés. Il ressort des entrevues que certains travaillent sur deux ou même trois types simultanément. Les résultats sont regroupés dans le

Tableau *11* et représentés dans la Figure 13 ci-dessous.

Types des projets	Total
Publics	14
Semi privés	6
Privés	8

Tableau 11 Types de projets sur lesquels travaillent les participants.

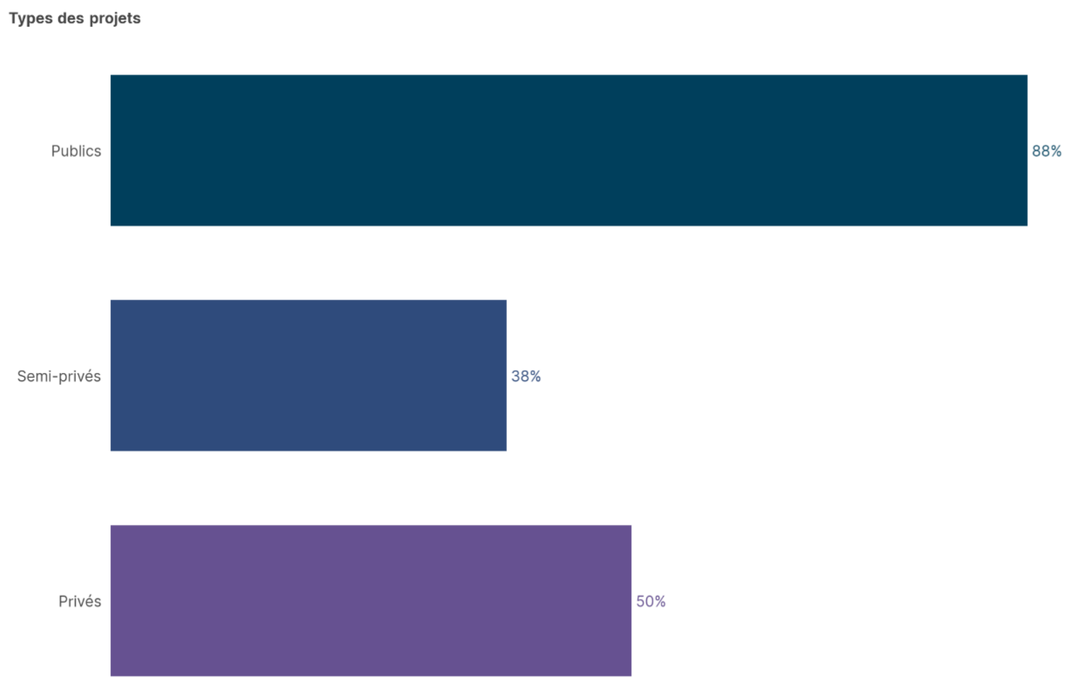


Figure 13. Types de projets des participants.

Quelle est la grandeur des projets sur lesquels vous travaillez ?

La grandeur des projets sur lesquels travaillent les participants est décrite selon une marge financière, allant de quelques millions à plus de cinq cents millions de dollars. Certains participants ont décrit la grandeur de la majorité de leurs projets, mais certains de leurs projets touchent à des échelles différentes. De ce fait, les résultats sont regroupés dans le Tableau **12** et sont représentés dans la Figure 14.

Grandeur des projets	Chiffres	Total
Petite	Jusqu'à 3M	4
Moyenne	Jusqu'à 10M	7
Grande	Jusqu'à 100M	8
Très grande	Jusqu'à 500M	7
Plus	Plus de 500M	2

Tableau 12. Grandeur des projets.

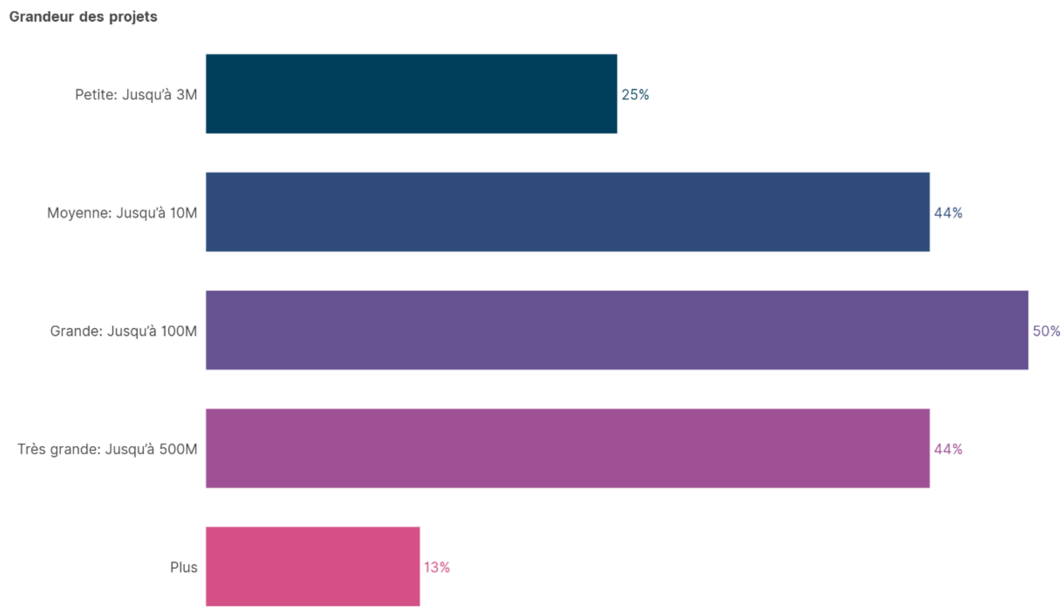


Figure 14. Grandeur des projets - Représentation graphique.

Avez-vous eu des projets où l'adaptabilité était requise ? Ou avez-vous déjà appliqué ce principe ?

Comme introduction au sujet principal des interviews qu'est l'adaptabilité, cette question visait à savoir si les intervenants appliquaient déjà ce concept dans leurs projets précédents. Il s'est avéré que la majorité des participants appliquaient déjà des notions d'adaptabilité dans leurs projets (environ 69% de l'ensemble des intervenants sondés). Certains y ont encore peu recours mais désirent intégrer ces approches progressivement dans leurs futurs projets. Une minorité des participants (13%) ne considère pas l'adaptabilité dans leurs projets. Les résultats sont représentés graphiquement dans la Figure 15.

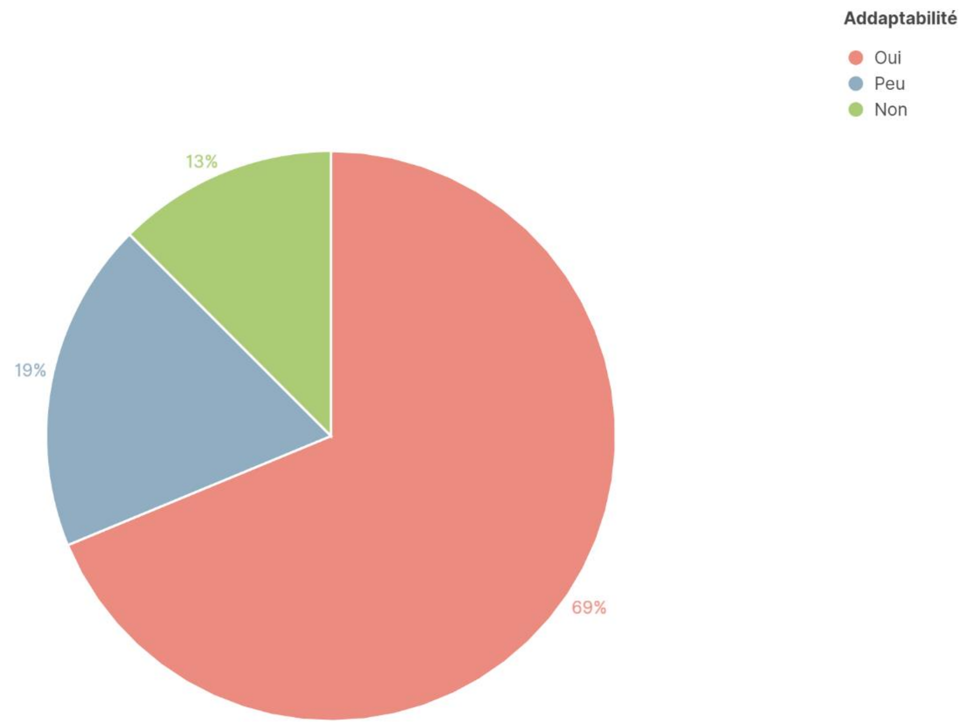


Figure 15. Application de l'adaptabilité dans les projets des participants.

Pour quels types de construction appliquez-vous l'adaptabilité ?

Pour la dernière question de cette deuxième partie, les participants qui appliquaient déjà l'adaptabilité dans leurs projets ont précisé les types de ces derniers. Il est important de souligner que l'adaptabilité est principalement appliquée pour l'aménagement des logements, ce qui est cité par plusieurs participants des divers organismes. En second lieu, l'adaptabilité est appliquée sur des projets résidentiels ou des projets de santé. Finalement, les autres types de constructions sont spécifiques et liés à des organismes précis. Les détails liés à l'adaptabilité seront traités de plus près dans la partie **Erreur ! Source du renvoi introuvable.** du présent document. Le Tableau **13** est un récapitulatif des données recueillies des entrevues.

Types de construction	Nombre	
Aménagement des logements	*Arc-1, Asso-1, Arc-3, Con-1, Ing-4, Arc-5*	6
Résidentiels	*Arc-2, Des-1, Arc-2, Prés-1*	4
Immeubles d'usage général	*Ing-1*	1

Commerciaux	*Prés-1*	1
Bâtiments temporaires	*Ing-2*	1
Projets de santé	*Ing-2, Ing-3, Dir-2*	3
Bâtiments issus du patrimoine religieux	*Dir-1*	1
Bâtiments universitaires	*Dir-2*	1
Communautaires	*Arc-3*	1

Tableau 13. Types de projets pour l'adaptabilité.

4.2.3. Partie 03 : Circularité

Cette partie comporte trois questions en relation avec la circularité. En y répondant, les données servent de base pour la partie 04 sur l'adaptabilité. La première question concerne la définition de la notion de circularité. Quant à la deuxième et la troisième, elles sont en lien avec les différentes stratégies de l'économie circulaire.

Êtes-vous d'accord avec cette définition ?

La circularité est un « système de production, d'échange et de consommation visant à optimiser l'utilisation des ressources à toutes les étapes du cycle de vie d'un bien ou d'un service, dans une logique circulaire, tout en réduisant l'empreinte environnementale et en contribuant au bien-être des individus et des collectivités » (« Enjeux et définition », s.d.)

Les participants sont tout à fait d'accord avec la définition proposée, en mentionnant les points suivants :

- C'est une définition vague, il serait mieux de la préciser au niveau du monde de la construction…*Ing-1*
- Identifier les ressources responsables et les parties prenantes…*Des-1*
- Inclure l'infrastructure…*Asso-2*
- Ajouter la notion du prolongement de la durée de vie…*Con-1*

Est-ce que le schéma des stratégies de l'ONU correspond à votre expérience ?

La Figure 16 représente les différentes stratégies de circularité selon l'ONU. Les participants jugent que ce schéma est complet et correspond parfaitement à leurs expériences.

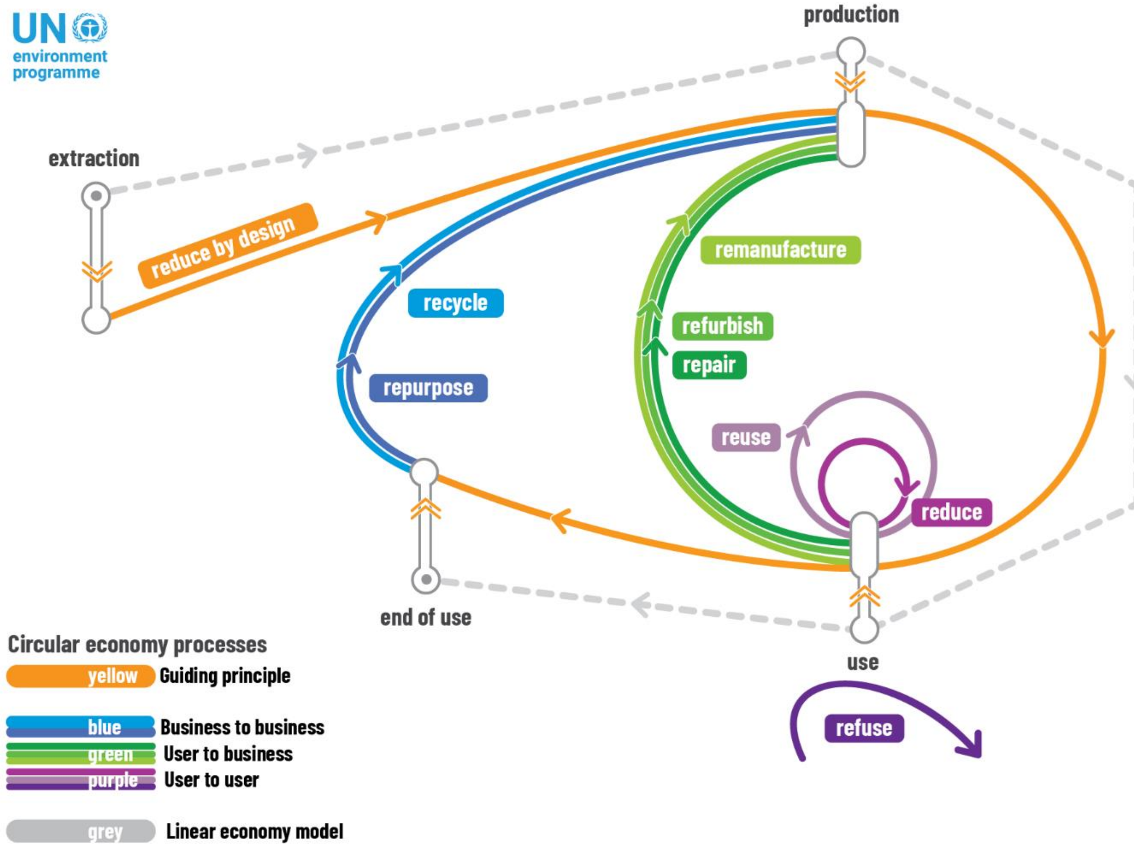


Figure 16. La circularité selon le PNUE (« Understanding circularity », 2019).

Cependant, ils ont mentionné les points suivants :

- Il serait intéressant de détailler les différentes stratégies et les adapter selon les besoins…*Arc-2*
- Il est important d'ajouter des pratiques plus adaptées pour l'industrie de la construction…*Des-1*
- Le schéma est complet et c'est celui à atteindre, mais il est loin d'être appliqué en réalité…*Ing-3*
- Il serait pertinent de le pousser plus loin…*Arc-3*

Les 9R de l'économie circulaire

Quant à la dernière question de cette troisième partie sur la circularité, elle concerne les différentes stratégies appelées '9 Rs de l'économie circulaire' (Potting, Hekkert, Worrell, & Hanemaaijer, 2017). Le but est de déterminer les stratégies qui sont plus efficaces pour l'adaptabilité de la construction. Bien évidemment, il est aussi demandé aux participants s'ils avaient eu recours à d'autres stratégies en plus de celles décrites dans la Figure 17.

Smarter product use and manufacture	**R0**	**Refuse**	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	**Rethink**	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
	R2	**Reduce**	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	**R3**	**Reuse**	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	**Repair**	Repair and maintenance of defective product so it can be used with its original function
	R5	**Refurbish**	Restore an old product and bring it up to date
	R6	**Remanufacture**	Use parts of discarded product in a new product with the same function
	R7	**Repurpose**	Use discarded products or its part in a new product with a different function
Useful application of materials	**R8**	**Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	**Recovery**	Incineration of material with energy recovery

Figure 17. Les stratégies de l'économie circulaire, (Potting et al., 2017).

Les résultats de cette question sont représentés dans la Figure 18 ci-après. Selon les participants, la stratégie la plus efficace pour l'adaptabilité est la R4 – Réparer, qui consiste à réparer et maintenir les produits pour pouvoir les utiliser avec leur fonction originale. La remise à neuf des produits – R5 est citée par 63% des participants, ce qui fait qu'elle soit la deuxième stratégie la plus efficace pour l'adaptabilité. Quant à la troisième stratégie, il s'agit de la réutilisation des produits qu'est la R3 avec 50%. En se basant sur ces résultats, ces trois stratégies sont les plus importantes. Tandis que la R9 est classée en dernier lieu avec seulement 13%. Les pourcentages sont représentés dans la Figure 18.

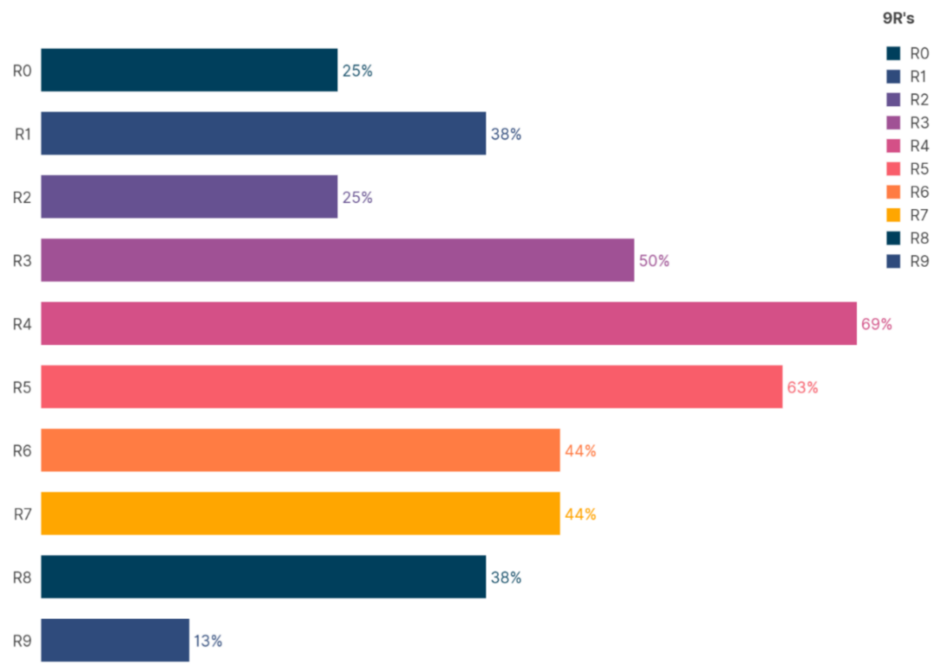


Figure 18. Représentation graphique des 9R'S de l'économie circulaire pour l'adaptabilité.

4.2.4. Partie 04 : Adaptabilité

Dans cette partie de l'entrevue, les questions sont orientées vers les pratiques de l'industrie pour l'adaptabilité. Le but est de comprendre si ce concept est déjà utilisé dans le contexte local et d'établir des liaisons entre les résultats théoriques et les pratiques industrielles.

Êtes-vous d'accord avec cette définition ?

« L'adaptabilité d'un bâtiment désigne la capacité d'un bâtiment à être modifié ou transformé pour répondre à l'évolution des besoins ou des conditions au fil du temps, avec un minimum de perturbations. »

La définition proposée semble correcte pour les participants. Ils sont tout à fait d'accord avec les termes utilisés mais ils soulignent les points suivants :

- Changer le 'minimum de perturbations' pour parler de sobriété ou pour mieux comprendre les impacts sur la structure ou sur les matériaux utilisés…*Arc-2*
- Mentionner les orientations de cette définition…*Des-1*
- Anticiper les perturbations pour les rendre minimes…*Dir-1*
- Ajouter les différents niveaux d'adaptabilité… *Asso-2*

À votre avis, comment pourrait l'adaptabilité être au service de la circularité ?

Les entrevues portent sur le lien de l'adaptabilité et la circularité dans la construction. Cette question établit une relation directe entre les deux concepts. Les participants ont exposé leurs points de vue et ont argumenté avec plusieurs exemples. Dans le

Tableau *14*, les avantages sont regroupés selon des catégories spécifiques. La prolongation de la durée de vie des composants est l'élément qui revient très souvent dans les réponses. Néanmoins, les participants ont mis le point sur la conception adaptable pour considérer la circularité depuis les premières phases du projet.

Catégories	Avantages	Participants
Cycle de vie	- Prolonger la durée de vie des composants pour les réutiliser comme une structure de bâtiment qui pourrait être réutilisée d'une autre façon - Favoriser la déconstruction	*Arc-1, Ing-2, Des-1, Asso-1, Dir-1, Dir-2, Arc-3, Con-1, Ing-4, Asso-2*
Matériaux ou Composants	- Le choix des composants qui peuvent être démontés et réutilisés à l'intérieur d'un même projet ou les transférer vers un autre projet - Requalification et transformation des matériaux	*Ing-1, Arc-5, Prés-1*
Conception	- Quantifier pour exercer une influence sur la conception des pièces multi usages - Réduire la consommation dès le début puis de repenser les façons de concevoir pour mieux déconstruire et mieux réutiliser les espaces et les matériaux - Penser à la récupération des matériaux pendant la conception	*Arc-2, Ing-3, Asso-2*
Développement durable	- Considérer le volet environnemental, social et économique	*Des-1*
Usages	- Concevoir des bâtiments multifonctionnels	*Arc-4*

Tableau 14. L'adaptabilité au service de la circularité.

À votre avis, quelles sont les raisons les plus fréquentes pour devoir apporter des changements dans un bâtiment ?

Selon les participants, la raison la plus fréquente pour apporter des changements dans un bâtiment est fonctionnelle. D'autres ont aussi fait référence aux raisons techniques et règlementaires, tandis que peu d'entre eux ont mentionné les raisons politiques. La Figure 19 est une représentation graphique des résultats obtenus. De plus, il y a des participants qui ont cité d'autres raisons qui ne sont pas déjà mentionnés auparavant.

Les participants *'Con-1'* et *'Ing-4'* ont ajouté les raisons esthétiques à celles susmentionnées auparavant. Une autre stratégie citée par '*Ing-4'*, est l'attraction. Le participant a expliqué le fait que certains clients apportent des changements en étant attirée par de nouveaux produits qui sont sur le marché. Il mentionne aussi le rôle du marketing dans ce contexte. En dernier, le participant '*Prés-1'* a fait références aux raisons économiques qui peuvent pousser les clients à modifier certaines parties de leurs habitations.

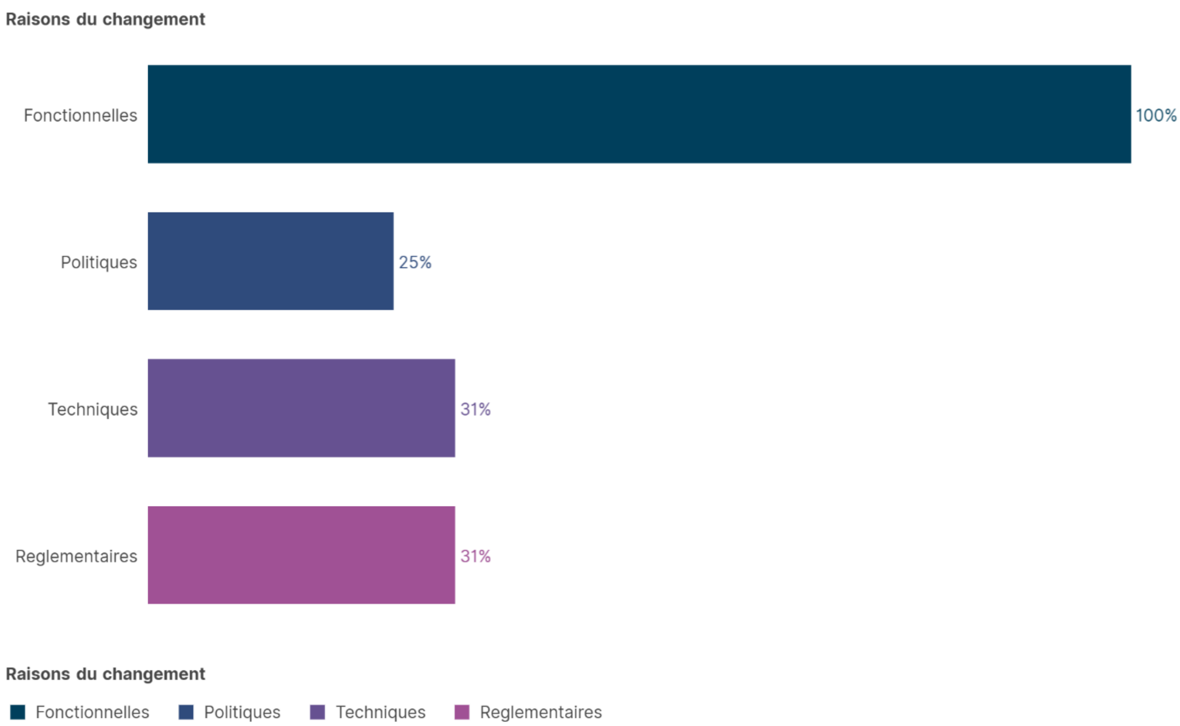


Figure 19. Les différentes raisons du changement.

À votre avis, quelles sont les difficultés pour l'adaptabilité dans les bâtiments ? Quelles sont les barrières ?

Comme tout nouveau concept, l'*adaptabilité fait face à plusieurs obstacles et barrières. Dans cette question, il était demandé aux participants de citer ceux qu'ils rencontrent le plus souvent dans leur pratique. Les obstacles sont catégorisés en cinq classes : techniques, économiques, politiques, règlementaires et sociaux comme représenté dans le* Tableau 15*. Certaines barrières sont citées plusieurs fois par les participants.*

Catégories	Barrières	Participants
Techniques	- Prédire les technologies du futur - Le choix des matériaux - Le manque de connaissances et d'expertises - Manque de planification - Conception inappropriée - Problèmes de logistique - La perspective à court terme sans prendre en compte la projection dans le futur - Pas de réflexions dans ce sens - Le manque d'informations - Pas de standardisation	*Dir-2, Ing-2, Arc-4, Con-1, Asso-1, Arc-1, Ing-4, Arc-5, Prés-1*
Économiques	- La notion du coût qui revient très souvent - Le retour sur investissement - Ça peut demander plus de temps pour le faire	*Arc-2, Ing-1, Ing-2, Des-1, Ing-3, Asso-1, Asso-2, Prés-1*
Politiques	- Les exigences des politiciens changent rapidement avec chaque mandat.	
Règlementaires	- Les règlements sont compliqués et strictes - L'absence des critères et des exigences de l'adaptabilité - Anticiper les besoins et les normes pour les mettre en œuvre	*Ing-1, Dir-2, Arc-3, Ing-3, Dir-1*
Sociaux	- La résistance aux changements - La sensibilisation des clients. - Le marché n'est pas encore prêt	*Cons-1, Ing-4, Dir-2, Con-1*

Tableau 15. Les barrières et les difficultés pour l'adaptabilité.

À votre avis, quels sont les avantages de l'adaptabilité ?

Plusieurs avantages de l'adaptabilité sont cités par les participants. Ils sont regroupés dans le Tableau 16 selon cinq catégories : techniques, environnementaux, sociaux, économiques et concurrentiels. Il est intéressant de constater que l'adaptabilité présente beaucoup d'avantages environnementaux. Ce volet est important dans le cadre de cette recherche pour établir le lien entre l'adaptabilité et la circularité. Cependant, d'autres avantages sont liés à l'aspect technique ou social. En dernier lieu, peu de participants ont mentionné les avantages économiques, à cause des coûts initiaux élevés.

Catégories	Avantages	Participants
Techniques	- Une meilleure planification du projet - Facilité de rénovation - Réaménagement plus rapide - Avoir un meilleur entretien - La capacité de changement rapide selon l'environnement	*Asso-1, Ing-1, Dir-1, Con-1, Ing-4*
Environnementaux	- Avoir de meilleurs impacts environnementaux - Améliorer l'empreinte écologique du projet - Une meilleure utilisation des matériaux : réutilisation, transformation et requalification - Prolonger la durée de vie d'un bâtiment	*Arc-2, Ing-2, Asso-1, Asso-2, Arc-4, Ing-3, Arc-1, Ing-1, Arc-3, Dir-2, Arc-5*
Sociaux	- Combler plusieurs besoins de logements multifonctionnels - Répondre aux besoins de l'usager - Soutenir le pilier social du développement durable	*Dir-1, Arc-2, Des-1*
Économiques	- Avantages liés aux coûts - Ne pas démolir et conserver certains éléments	*Ing-3, Prés-1*
Concurrentiels	- Proposer des conceptions adaptables peut être un bon outil de se différencier des autres entreprises - Avoir un bon marketing	*Prés-1*

Tableau 16. Avantages de l'adaptabilité.

L'adaptabilité est-elle applicable aux anciennes constructions ? Qu'est ce qui rend les bâtiments existants plus difficiles à adapter ?

L'adaptabilité s'applique aux anciennes constructions, les participants confirment que l'adaptabilité est applicable aux anciennes constructions. Néanmoins, ils mentionné plusieurs difficultés qui sont regroupées dans le Tableau 17.

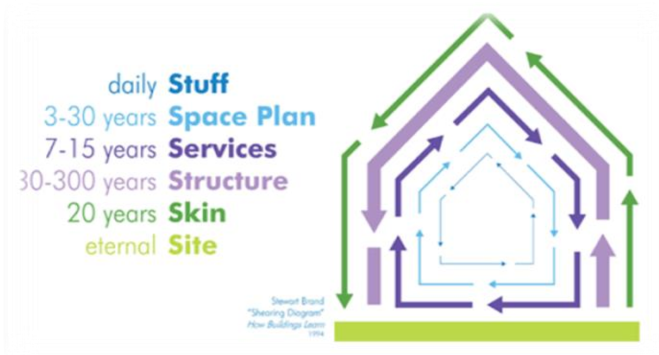
Catégories	Difficultés	Participants
Techniques	- Les besoins qui changent de dans le temps - L'emplacement de certains équipements qui compliquent l'aménagement intérieure - Ne pas pouvoir intervenir sur tous les éléments, mais seulement sur certains comme les systèmes intérieurs, d'où certaines restrictions - L'aménagement des espaces habitables à l'intérieur des bâtiments déjà construits - La complexité liée à la logistique et aux projets - Les techniques de construction qui changent ce qui fait moins de flexibilité - Les bâtiments n'ont pas été conçus depuis le début pour supporter ces changements - L'absence des données des anciennes constructions - Ne pas pouvoir prédire les besoins du futur - Les anciennes constructions ne tiennent pas compte des impacts environnementaux - L'absence d'expertise et de connaissances - L'évaluation des anciennes constructions pour pouvoir changer l'usage - Les modes de construction qui évoluent dans le temps	*Arc-1, Arc-2, Ing-1, Ing-2, Des-1, Ing-3, Dir-1, Dir-2, Asso-2, Arc-4, Asso-1, Arc-5*
Règlementaires	- Les normes et les réglementations qui évoluent avec des critères difficiles à satisfaire	*Arc-1, Ing-2, Arc-3, Asso-2, Con-1, Ing-4, Arc-5, Prés-1*
Sociaux	- La sensibilisation et le partage d'informations entre les différentes parties prenantes - Les attentes qui changent dans le temps	*Des-1, Arc-5*
Économiques	- Les coûts initiaux sont élevés	*Arc-3, Asso-2, Arc-4, Ing-4, Arc-5, Prés-1*

Tableau 17. Difficultés liées à l'adaptabilité des anciennes constructions.

En analysant les résultats présentés dans le Tableau 17, les difficultés techniques sont majoritairement citées par les participants. L'absence des données des anciennes constructions est l'un des problèmes primordiaux étant donné que celles-ci ne sont pas conçues depuis le début pour supporter les changements. L'importance d'une conception adaptable dans les premières phases du cycle de vie pourrait répondre à ces difficultés. Néanmoins, pour pousser la recherche plus loin dans ce sens, des leviers pourraient être présentés pour répondre aux différentes difficultés qu'ont citées les participants.

Sur la base du modèle de Duffy (1990), quelles sont les couches du bâtiment qui pourraient être plus adaptables d'un point de vue pratique ?

Le modèle de Duffy illustré dans la Figure **20** est présenté aux participants afin de cerner les couches qui sont le plus efficace pour l'adaptabilité. Les résultats de cette question sont représentés graphiquement dans la Figure 21.



Layer	Description	Time scale
Site	Geographic setting	Eternal
Structure	Load bearing elements	30-300 years
Skin	Facade	20 years
Services	Plumping, HVAC	7-15 years
Space plan	Furniture, equipment position	3-30 years
Stuff	Furniture, equipment position	Daily

Figure 20. Brand Steward,

Shearing Diagram, How buildings learn, 1994.

Selon les participants, les deux couches qui sont les plus efficaces pour l'adaptabilité sont les services et la planification avec une fréquence de 69%. Les autres couches sont moins citées en raison de la complexité technique ou même des obstacles règlementaires.

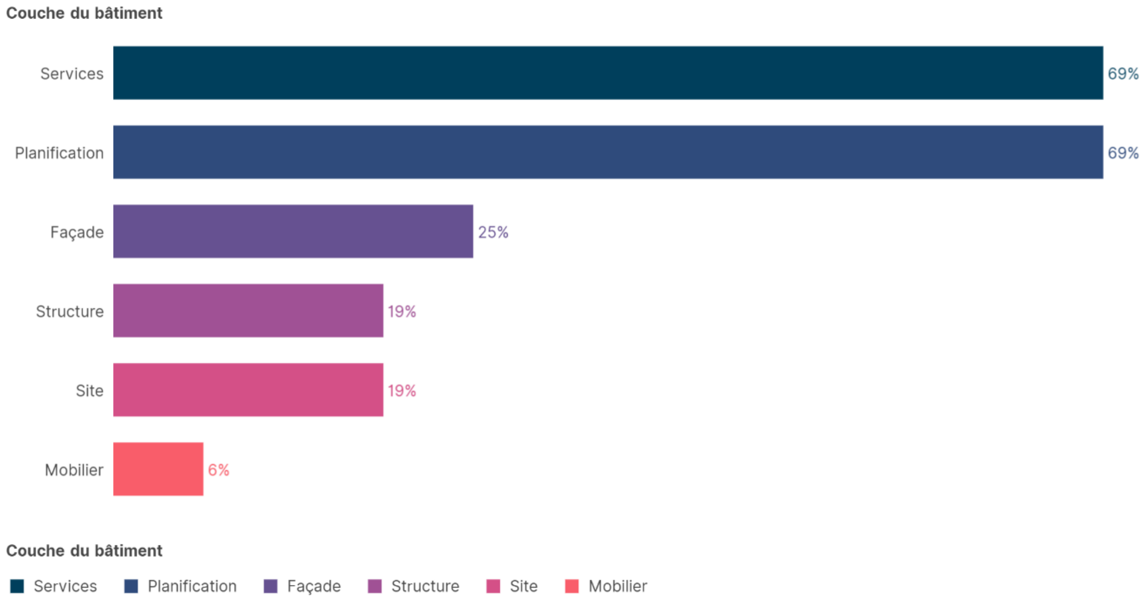


Figure 21. Représentation graphique des couches les plus utilisées pour l'adaptabilité.

D'après votre expérience, laquelle de ces couches est la plus problématique, la plus facile et la plus efficace ? Laquelle est la plus fréquente ?

Étant donné le niveau de complexité de chaque couche, cette question vise à comprendre ce qui plus problématique ou plus facile. Dans ce sens, les participants ont répondu à la question en précisent les couches qui sont les plus : problématiques, faciles, efficaces et fréquentes. Les résultats sont représentés dans la Figure 22 ci-après. Cependant, certains des participants n'ont pas répondu à toutes les parties de cette question. La représentation des résultats est faite selon le nombre de réponses obtenues pour chaque partie.

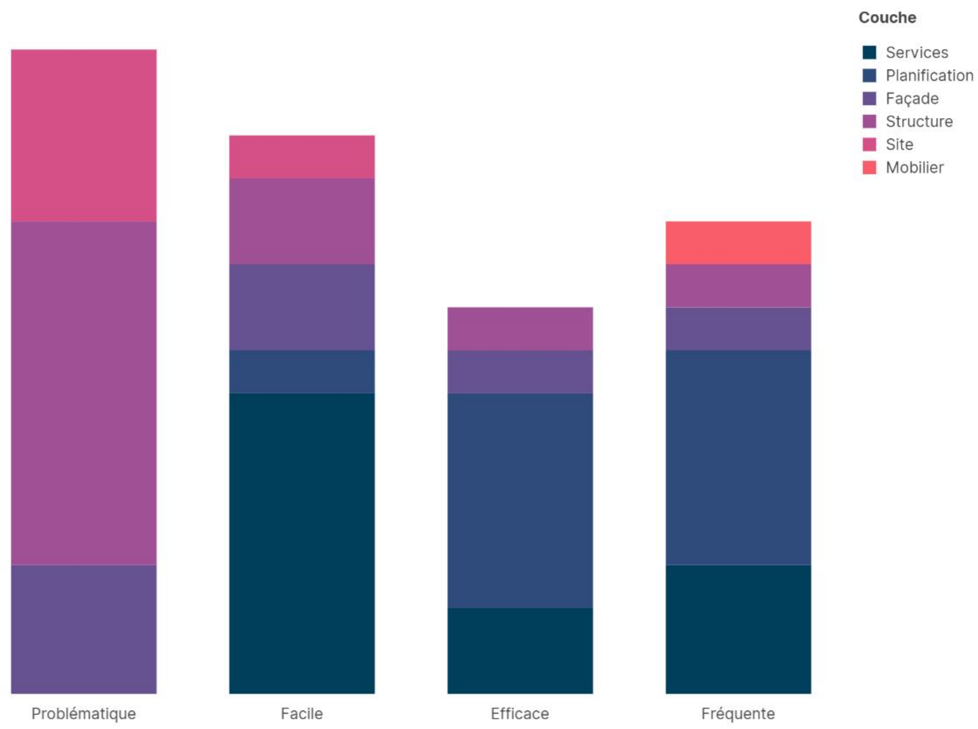


Figure 22. Les différentes couches du bâtiment.

Selon les résultats obtenus, la couche la plus problématique est la structure, ceci revient à la complexité des travaux à effectuer et les règlementations strictes. En ce qui concerne à la couche la plus facile, il s'agit principalement des services. Les équipements peuvent être modifiés facilement et cela ne demande pas beaucoup de changements ou des frais. Quant à l'efficacité et la fréquence des couches, la configuration intérieure étant la plus citée dans les deux cas. Justifiée par les attentes des clients et de la disponibilité des solutions pour y répondre, la planification est la couche qui revient le plus en termes d'adaptabilité.

Sur la base du concept de Robert Schmidt (2016), pour concevoir le bâtiment adaptable, quels types de changements sont les plus courants ?

Il existe plusieurs types de changements à apporter dans une construction. Selon le concept de Robert Schmidt (Schmidt III & Austin, 2016b), il existe six catégories de changements, récapitulées dans la Figure 23. De ce fait, cette question vise à comprendre les différents types de changements qui sont le plus courants dans les pratiques locales.

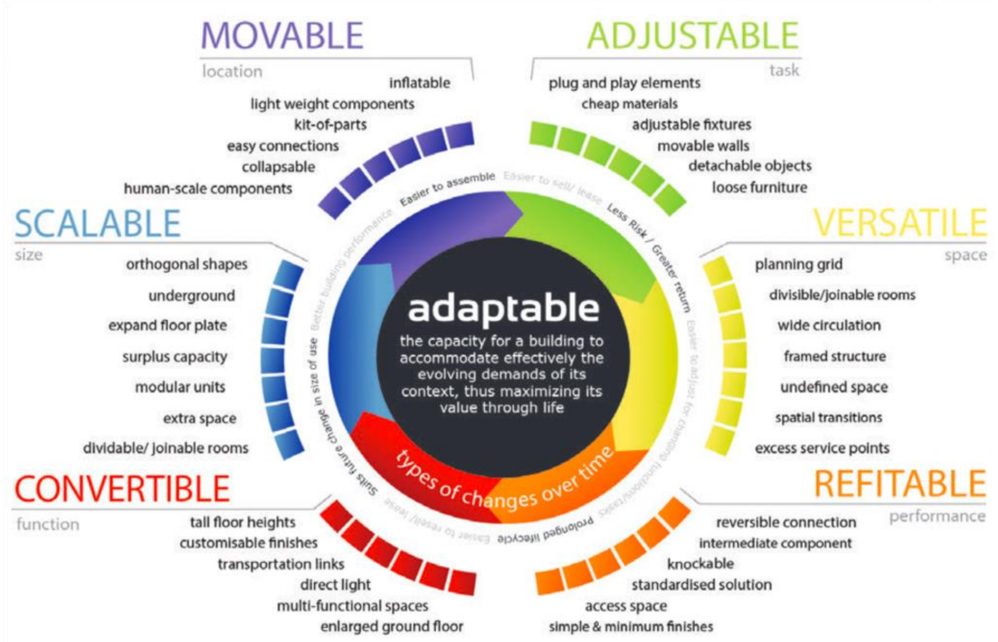


Figure 23. Adaptability types, Adaptable FUTURES (2012).

Selon les participants, les changements les plus courants concernent les espaces polyvalents d'environ 81%. Ceci revient à la nécessité d'avoir des espaces multi-usages qui peuvent être considérés selon les besoins des occupants. Quant à la fonction des espaces, elle est en deuxième place avec 38%. La fonction convertible vise à avoir des bâtiments ou des espaces multifonctionnels. Enfin, en dernier lieu, avec seulement 13%, la performance raisonnable qu'est la possibilité de mise à niveau en cas de modification des performances d'un bâtiment. La représentation de ces résultats est illustrée dans la Figure 24.

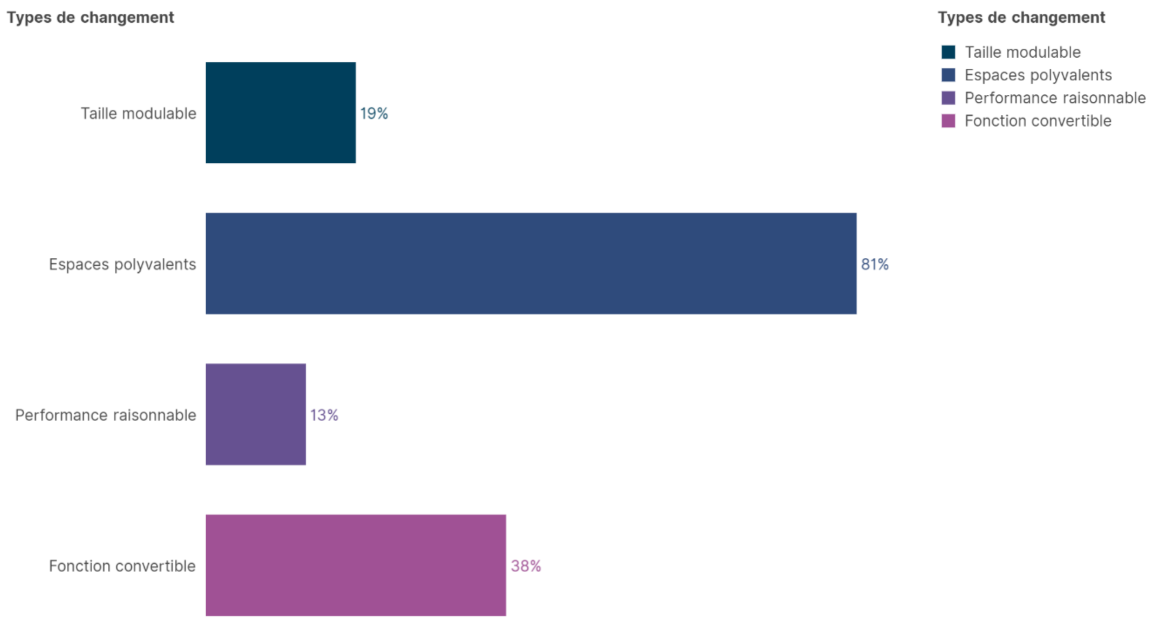


Figure 24. Types de changement pour l'adaptabilité.

Quels types d'obstacles rencontrez-vous au cours du processus de conception pour l'adaptabilité ?

Il existe plusieurs obstacles qui peuvent surgir lors du processus de conception. Trois types d'obstacles sont présentés aux participants. Les résultats sont représentés dans la Figure 25.

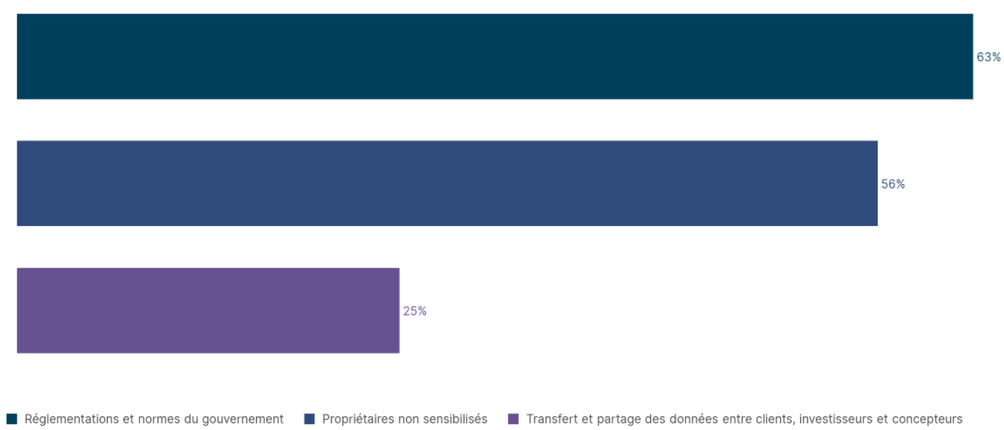


Figure 25. Types d'obstacles rencontrés au cours du processus de conception adaptable.

Les règlementations et les normes du gouvernement semblent être l'obstacle le plus cité par les participants. Avec environ 63%, les participants mentionnent que les règlementations sont parfois trop strictes, ce qui pourrait être un obstacle dans certains cas. Le second obstacle qui revient très souvent est la sensibilisation des clients. Ces derniers ne sont pas conscients des enjeux et des solutions appropriées. Cependant, il est difficile de les convaincre d’investir dans un tel concept. En dernier lieu, avec seulement 25%, le transfert et le partage de données ne semble pas être un obstacle que rencontrent souvent les praticiens.

Suivez-vous des règles de certification pour concevoir l'adaptabilité ? Si oui, veuillez en citer quelques-unes.

Les participants ne suivent aucune règle de certification pour l’adaptabilité. Cependant, certains ont mentionné la certification LEED qui contient des critères qui peuvent être au service de l’adaptabilité. Novo Climat et WELL est aussi cité dans le même contexte. Ils ont aussi précisé l’importance d’avoir une certification pour l’adaptabilité.

Évaluez-vous le taux d'adaptabilité dans vos projets ?

Tous les participants ont mentionné qu’ils n’évaluent pas le taux d’adaptabilité dans leurs projets et affirment ne pas connaitre les différents modèles d’évaluation identifiées dans la revue de la littérature qui leurs sont présentés lors de l’entrevue. Néanmoins, certains des participants sont intéressés d’en savoir plus sur ces modèles d’évaluation du taux de l’adaptabilité.

Comment faites-vous pour sensibiliser les clients ou les propriétaires publics à l'adaptabilité des bâtiments et aux stratégies associées ?

La sensibilisation des clients s’avère être un point essentiel, il est cité comme deuxième obstacle auquel fait face l’industrie de la construction. Pour y remédier, certains organismes essayent de les convaincre avec des études de cas ou en mentionnant les exigences dans les contrats. Tandis que d’autres n’essayent pas de sensibiliser les clients ou tentent d’autres méthodes que celles susmentionnées.

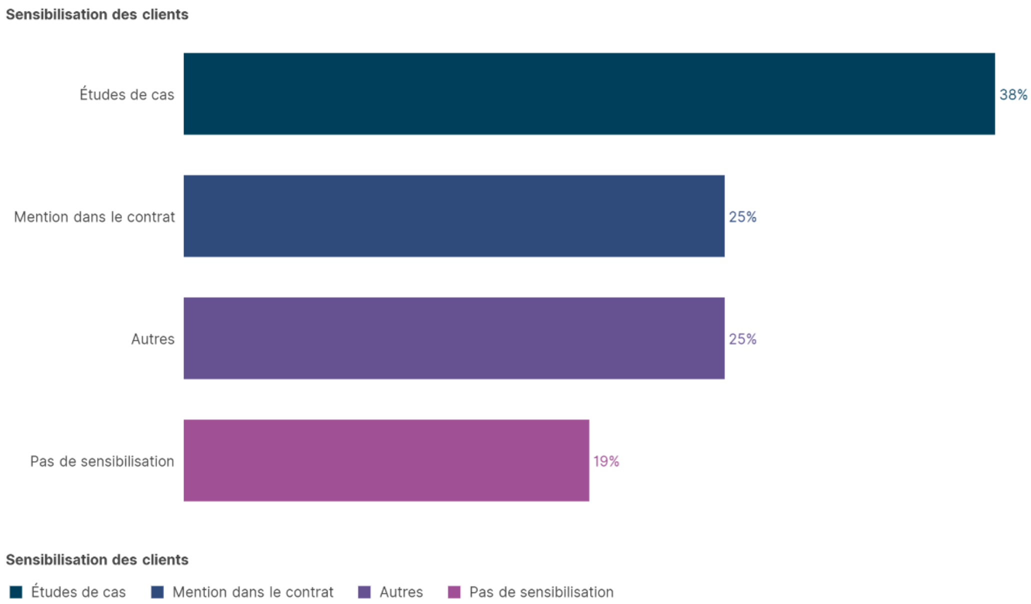


Figure 26. Méthodes de sensibilisation des clients.

Les résultats sont illustrés dans la Figure 26. La première solution citée avec 38% des participants concerne les études de cas contre seulement 25% des mentions dans les contrats. Environ 19% des participants ont mentionné qu'ils ne font aucune sensibilisation pour les clients. Cependant, en plus des études de cas et des mentions dans les contrats, les participants ont aussi cité :

- Supporter et encourager ceux qui ont une telle vision…*Arc-1*
- Comprendre les besoins du client pour suggérer de nouvelles approches… *Ing-1*
- Proposer des formations et des initiatives pour aider les entreprises qui ont des projets avec des exigences environnementales…*Des-1*
- Établir les objectifs et les ajouter dans le processus de conception intégré…*Ing-3*
- Prévoir le bâtiment dans le temps pour voir comment il peut évoluer selon les phases et les usagers futurs…*Arc-3*
- Commencer par sensibiliser les responsables…*Ing-4*

4.2.5. Partie 05 : Attentes et exigences des clients et du gouvernement

La dernière partie de l'entrevue porte sur les attentes et exigences des clients et du gouvernement. Cinq questions se posées aux participants, les réponses sont récapitulées dans ce qui suit.

Est-ce que vos clients ont des attentes par rapport à l'adaptabilité des projets? Si oui, y a-t-il des demandes spécifiques qui sont récurrentes ?

Certains des participants ont mentionné que leurs clients n'ont pas ou ont très peu d'attentes par rapport à l'adaptabilité des projets. Il existe des demandes spécifiques mais elles ne sont pas forcément récurrentes. Néanmoins, d'autres ont donné des exemples :

- Le nouveau mode de vie post pandémique dans le résidentiel…*Arc-2*
- La plupart des besoins de l'adaptabilité sont fonctionnels…*Ing-1, Dir-1*
- La majorité des cas sont des bâtiments modulaires…*Ing-2*
- Les attentes récurrentes concernent souvent l'aménagement intérieur…*Asso-1, Ing-4*

Selon votre expérience, existe-il une règlementation qui exige ou encourage la conception adaptable ?

Les participants affirment qu'il n'existe aucune réglementation qui exige ou qui encourage la conception adaptable, et qu'il est serait vraiment intéressant d'en avoir. Certaines ont souligné qu'il y a des standards ou des certifications comme LEED, qui n'ont pas nécessairement un objectif d'adaptabilité mais qui comportent des critères dans ce-sens.

Est-ce qu'il vous est arrivé de promouvoir une approche adaptable dans la conception des projets sans que cela ne soit demandé ou exigé par une autre des parties prenantes ?

En réponse à cette question, la majorité des participants affirment avoir proposé des approches adaptables dans la conception sans que cela ne soit demandé, ces approches sont différentes :

- Encourager les manufacturiers pour penser à de nouveaux concepts de déconstruction des assemblages et de la réutilisation…*Arc-1*
- Proposer aux clients des conceptions modulaires de bâtiments…*Ing-2*
- Penser à des démarches adaptables pour changer d'usages ou de proposer des espaces multifonctionnels…*Arc-2, Dir-1*
- Proposer des conceptions avec des partitions amovibles qui sont démontables et réutilisables…*Ing-1*
- Faciliter les réaménagements intérieurs…*Ing-3*
- Participer dans l'environnement de travail en avant-garde…*Asso-2*

Sur quels critères se basent les conceptions adaptables que vous proposez aux clients ?

Certains des participants ne proposent pas de conceptions adaptables, les autres ont mentionné les critères suivants :

- Proposer des espaces plus durables pour éviter d'en rajouter…*Arc-2*
- Espaces amovibles…*Arc-2*
- Le critère fonctionnel…*Ing-1*
- Le principe de la préfabrication pour réduire les impacts environnementaux et avoir une meilleure durée de l'échéancier…*Ing-2*
- Prise en compte des trois piliers du développement durable : environnemental, économique et social…*Ing-1, Des-1, Con-1*
- La réutilisation des matériaux et la proposition des espaces multifonctionnels…*Ing-3*
- La flexibilité est le critère principal…*Asso-1*
- Prévoir de la capacité supplémentaire au niveau des services électromécaniques et faire le bon choix des équipements…*Dir-2*
- Répondre aux plus grands nombres d'usages selon les besoins des clients…*Dir-1, Arc-3*
- Multifonctionnalités et aménagement…*Asso-2*
- Réutilisation…*Ing-4*

Comment décririez-vous les impacts que peuvent avoir les règlements en lien avec la protection patrimoniale sur une approche adaptable dans un bâti existant ?

Les règlements en lien avec la protection patrimoniale semblent parfois être un obstacle pour une approche adaptable dans un bâti existant. Les exigences sont strictes et peuvent être difficile à atteindre. Cependant, elles peuvent aussi soutenir la circularité. Les avis se partagent sur ce sujet, les participants ont répondu comme suit :

- L'impact pourrait être positif en ce qui concerne la réutilisation des bâtiments existants…*Arc-1, Dir-2, Arc-5*
- Ça peut être difficile et compliqué…*Ing-3, Dir-1, Ing-4, Arc-5*
- C'est intéressant pour protéger et conserver le plus de bâtiments patrimoniaux…*Arc-2*
- Protéger l'enveloppe du bâtiment existants, et parfois même l'intérieur…*Ing-1*
- La conservation de la façade rend parfois l'adaptabilité plus compliquée…*Ing-2*
- La protection des bâtiments en faisant des analyses de cycle de vie…*Asso-1*
- Il faut voir l'interaction et les liens entre la protection patrimoniale, la circularité et l'adaptabilité et non pas chacune à part…*Dir-2*

- Les règles sont tellement strictes que ça limite tout ce qui pourrait se faire en termes d'adaptabilité…*Arc-3*
- Le patrimoine respecte les lieux et exige de pas toucher à certaines parties des constructions…*Arc-4*
- La conservation de la culture…*Asso-2*
- Il existe un lien entre l'adaptabilité et la protection patrimoniale, l'un n'empêche pas l'autre…*Con-1*

Selon votre expérience, est-ce que des processus de conception ou de gestion de projet spécifiques sont plus adaptés (ou même nécessaires) pour assurer le succès d'un projet adaptable ?

Cette dernière question de l'entrevue porte sur la nécessité d'adopter des processus de conception ou de gestion de projet spécifiques pour assurer le succès d'un projet adaptable. Les participants ont affirmé cette nécessité et ont fait référence au processus de conception intégré. Les éléments soulignés sont les suivants :

- Il serait important de pousser la vision à long terme en tenant compte de la durée de vie des composantes pour penser à la fin de vie ou la réutilisation sera envisageable…*Arc-1*
- Ça pourrait être mis en œuvre dans les processus pour assurer la finalité de démarche adaptable…*Arc-2*
- Avoir une sensibilisation sur le type de système de construction qui doit être choisi par les concepteurs…*Ing-1*
- Inclure les opportunités ou des options de systèmes adaptables dans les modes contractuels…*Ing-2*
- Penser à un processus de collaboration intégré…*Des-1*
- Avoir la traçabilité pour pouvoir suivre l'avancement du projet…*Des-1*
- Les processus de conception intégrée dès le départ pour fixer les objectifs et les enjeux du projet en amont et établir le PFT…*Ing-3*
- Les procédures sont déjà extrêmement lourdes, il ne s'agit pas d'en ajouter d'autres mais dans le fait d'avoir des concepteurs habiles et agiles qui sont capables d'avoir les différentes contraintes en tête…*Dir-1*
- Faire en sorte que les professionnels, les concepteurs et les utilisateurs soient en contact…*Dir-2*
- Essayer de voir le projet de plusieurs points de vue et d'essayer de tester plusieurs scénarios…*Arc-3*
- La conception en amont de la gestion de projet doit être alignée avec les objectifs dès le début…*Arc-4*
- Une conception intégrée soutenue par les normes et les règlementations…*Asso-2*

4.3. Cadre de travail conceptuel proposé

As previously mentioned, this study aims to establish strategies for building's adaptability that support both circular economy and sustainability due to their interconnected nature. Recognizing the three foundational pillars of sustainability—economic, environmental, and social—this research underscores the importance of addressing not only the tangible elements of adaptable architecture but also the contextual contingencies within the suggested framework.

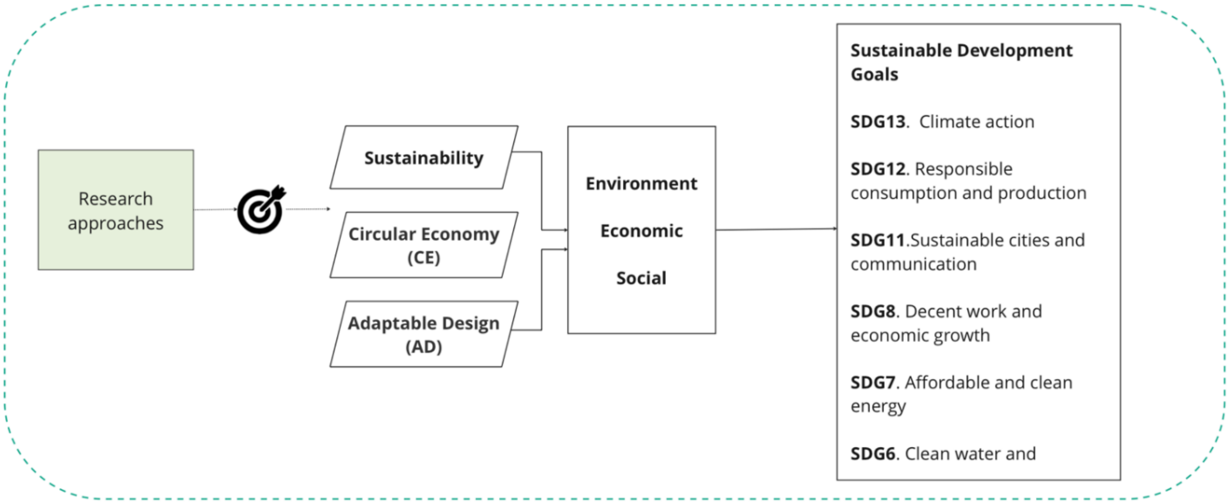


Figure 27 Contribution of three topics Design for adaptability, circular economy and sustainability to six UN sustainable development goals

4.3.1. Process of designing for adaptability and stakeholders' role

In the pursuit of constructing adaptable buildings, it is imperative to initiate the design process with a clear focus on adaptability. This approach necessitates the active involvement of stakeholders from the outset, ensuring their awareness is heightened and their input is integrated into the selection of viable strategies. Engaging stakeholders not only brings valuable insights but also fosters a collaborative environment where recommendations can be solicited and deliberated upon during the early stages of the design process.

As the design evolves, a thorough evaluation of the available options is critical to bolster the building's adaptability. This evaluation is twofold: firstly, it assesses the recommendations and the implementation of adaptable strategies; secondly, it reviews the preliminary design to confirm its adherence to the principles of the circular economy and sustainability. Additionally, this appraisal determines whether the design meets the occupants' needs, fits within the allocated budget, and aligns with the contextual demands as well as established building standards and codes. Expanding on this, the process should incorporate a methodical analysis to ensure that the final design is not only flexible but also economically and environmentally viable, thereby satisfying the multifaceted criteria of an adaptable building. The figure below shows the process of building design and parallels with this process in the pink process researching to find the good criteria based on the requirements and local regulations need to be done, in this process in two phases stakeholders (owner, investor, users, etc.) can contribute to the design process.

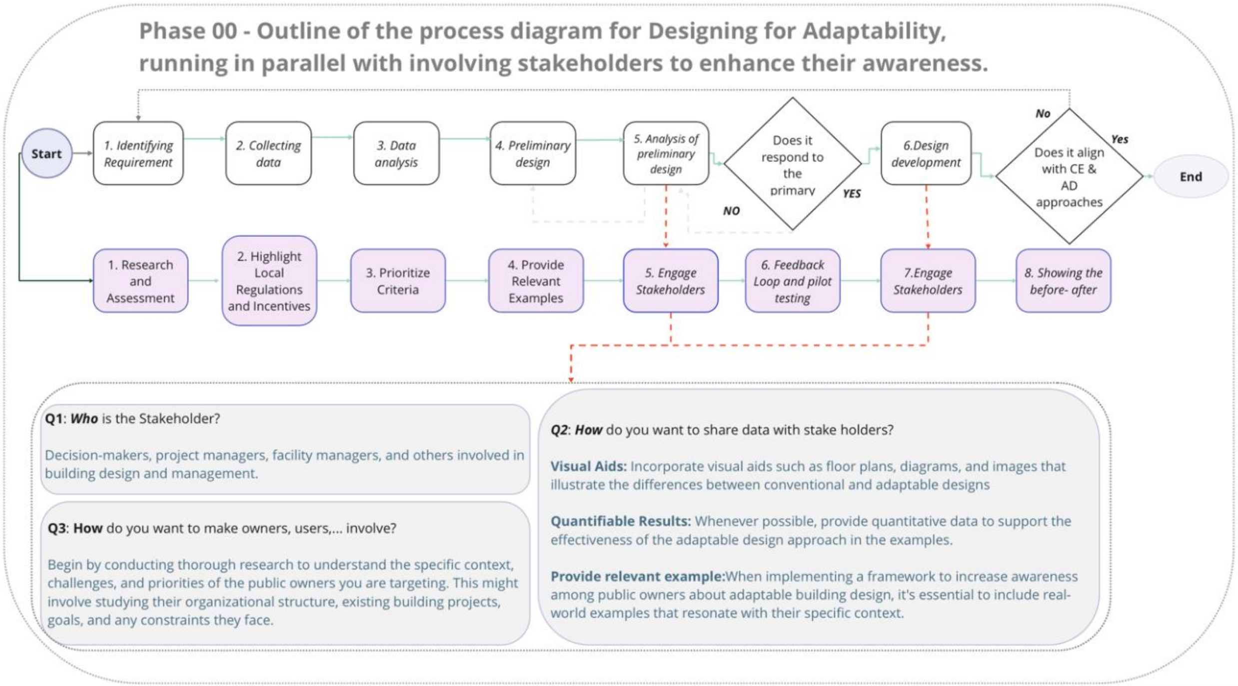


Figure 28 Process of design for adaptability and engaging stakeholders and evaluation phases

To enhance the adaptability of buildings, a comprehensive framework is essential, one that encompasses a spectrum of strategies tailored to each segment and component of a building's lifecycle. This spans from the initial selection of materials, through to the design phase, continuing into maintenance and refurbishment, and culminating at the end of the building's useful life. The central query of our research is the methodology by which adaptability can be augmented. In response, this study proposes a strategic framework designed to be integrated into the architectural design process. This framework is constituted by a set of criteria that serve as a strategic guide for applying adaptability principles to the design of a building. By adopting this structured approach, the research aims to operationalize adaptability in the built environment, ensuring that buildings can evolve in response to changing requirements over time while maintaining their functional and structural integrity.

4.3.2. Decomposition from shearing layers to design criteria and sub-criteria in the framework

The theory of shearing layers, conceptualized by architect Frank Duffy and later expanded by Stewart Brand in his book "How Buildings Learn," is pivotal in understanding the dynamic and evolving nature of buildings. It posits that a building comprises several layers that have different lifespans and needs for change: from the site, which remains constant, to the structure, skin, services, space plan, and stuff (furnishings), each changing at its own pace. Recognizing these layers is crucial as it allows architects, builders, and owners to design and construct buildings that can adapt to changing requirements over time. It emphasizes flexibility, anticipates future modifications, and thus significantly contributes to sustainability. By accommodating change efficiently, buildings can stay functional and relevant, reduce waste, and support the various ways humans use and interact with built spaces across decades or even centuries. Therefore, In the proposal framework, the initial column is dedicated to segmenting the building into distinct layers. In the framework's second column, each layer is refined and segmented into key criteria, drawing from the information on adaptable building strategies found in the book "Adaptable Architecture." (Schmidt III & Austin, 2016a). Design criteria function as key conceptual benchmarks that inform architects about the multifaceted nature of a building, including its capacity for adaptability. These criteria present a framework for integrating adaptability into the overall design process – although they are comprehensive, encompassing more than just adaptability, recognizing it as intertwined with a spectrum of other essential design elements. Some of these criteria and sub-criteria can contribute together and they have interconnection. It is possible to find different sub-criteria for one approach and depending on the design and situation of the building and the budget, decision-makers can find out which criteria work better for the building and align with the requirements of the building. Some of the sub-criteria need to be applied to the building from the beginning and some others are also possible to be applied also for existing buildings to make them more adaptable. Overall, all these criteria are regarded as the physical aspects of the adaptable building. The following section, titled "Contextual Contingencies Framework," addresses the significance of non-physical criteria such as heritage conservation, environmental safety, and affordability. The following section, titled "Contextual Contingencies Framework," addresses the significance of non-physical criteria such as heritage conservation, environmental safety, and affordability.

4.3.3. Proposed Design-for-Adaptability Framework

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Adaptable building					
Layers	Criteria	Numbers	Sub-criteria	Explanation	References
Services	A. Access	A.1	Access to building	Access to a building plays a crucial role in enhancing its adaptability. Adaptable buildings are designed to evolve over time, accommodating changes in use, technology, and the environment. Easy and flexible access to different parts of a building facilitates this adaptability. It allows for easier renovations, modifications, and repurposing of spaces without major disruptions or structural changes. This flexibility in access helps in extending the building's economic viability, reducing maintenance costs, and addressing changing socio-economic needs. Moreover, adaptable buildings, through their flexible access features, can respond more effectively to the needs of diverse user groups, thereby contributing to a more inclusive and sustainable built environment.	Slaughter, 2001; Webb et al. https://doi.org/10.1108/IJBPA-09-2017-0045
		A.2	Specified acccess for disablers	In the context of accessible or adaptable buildings, the focus is typically on providing features and facilities that ensure equal access and usability for individuals with disabilities. Such as Ramps and Elevators, Accessible Restrooms, Accessible Parking.	ADA Standards for Accessible Design. ADA.gov. (n.d.
		A.3	Reuse of stairs and elavators	Refers to designing or retrofitting a building in a way that allows existing staircases and elevators to continue serving their intended purposes efficiently, even as the building undergoes changes or adaptations to meet evolving needs or regulations.	Hamida, M.B., Remøy, H., Gruis, V., & Jylhä, T. (2023). Circular building adaptability in adaptive reuse
		A.4	Location of of the vertical access	refers to the strategic placement or positioning of elements such as stairs, elevators, ramps, and other vertical circulation mechanisms within a building to ensure ease of movement and accessibility for occupants and visitors	Hamida, M.B., Remøy, H., Gruis, V., & Jylhä, T. (2023). Circular building adaptability in adaptive reuse
	B. Insulation	B.1	Fire safety/ resistancy	Fire safety and resistance in insulation significantly contribute to a building's adaptability by ensuring enhanced safety, regulatory compliance, reduced damage, lower insurance costs, and greater flexibility for various uses. Fire-resistant insulation materials slow down the spread of flames, enhancing occupant safety and reducing structural damage in case of a fire. Building codes and regulations often mandate fire-resistant insulation, ensuring legal compliance and reducing the risk of costly retrofits. Lower insurance premiums for buildings with effective fire safety features provide financial adaptability. Fire-resistant insulation also promotes sustainability, resilience, and durability, making buildings better equipped to face various challenges.	Code Council (ICC), "International Building Code," 2021 edition. National Fire Protection Association (NFPA), "NFPA 101: Life Safety Code," 2018 edition.
		B.2	Energy modeling	Energy modeling is a powerful tool that can significantly contribute to the adaptability of a building in several ways. By simulating and analyzing energy performance under various scenarios, it helps inform design decisions and optimize energy-efficient features, which can lead to long-term adaptability benefits.	ASHRAE, "ASHRAE Standard 209-2018: Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings."
		B.3	Moisture control	Moisture control in insulation significantly contributes to a building's adaptability. It prevents issues like mold growth, structural damage, and reduced insulation performance, ensuring the longevity of the structure. Effective moisture control also supports energy efficiency, making the building adaptable to changing energy regulations and market demands. Furthermore, it facilitates renovations and modifications, as well as enhances indoor comfort and occupant satisfaction. Overall, proper moisture management in insulation is a fundamental aspect of creating a resilient and adaptable building.	ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Handbook: The ASHRAE Handbook is a comprehensive resource for HVAC and building
		B.3	Insulation material durability	Insulation material durability greatly contributes to a building's adaptability. Durable insulation lasts longer, reducing maintenance needs and costs. Durability enhances a building's resilience, enabling it to withstand adverse conditions. Durable insulation also helps maintain the building envelope's integrity, making the structure comfortable and adaptable for various uses.	(Jones et al., 2018) , (Huang et al., 2020) , (Lstibůrek and Carmody, 2012)
		B.4	insulation integrity	Insulation integrity significantly contributes to a building's adaptability by ensuring sustained energy efficiency, thermal comfort, and moisture control. It supports the structural integrity of the building, enhancing its overall stability and longevity. Maintaining insulation integrity reduces the need for frequent repairs, optimizing long-term cost-effectiveness and adaptability. Proper insulation management is crucial for creating a comfortable, durable, and efficient building that can easily adapt to varying climates and purposes.	Balaras, C. A., Droutsa, K., Argiriou, A. A., & Asimakopoulos, D. N. (2007). Analysis of energy consumption and life cycle cost in residential buildings: The case study of Greece. Energy and Buildings, 39(5), 508-514.
		B.5	Green roof insulation	Green roof insulation, which involves planting vegetation on a building's rooftop, offers several benefits that contribute to the adaptability of the structure. Firstly, it enhances	(Getter & Rowe, 2006), (VanWoert et al., 2005), (Yang & Yu, 2019)
		B.6	High insulation R-values	High insulation R-values, which represent the thermal resistance of a building's insulation materials, offer numerous advantages that significantly contribute to a building's adaptability. Firstly, they enhance energy efficiency by minimizing heat transfer, reducing heating and cooling costs, and allowing the building to meet evolving energy efficiency standards and regulations .Secondly, higher R-values contribute to consistent indoor comfort by preventing temperature fluctuations and drafts, making the building adaptable for various climates and occupant preferences.	(U.S. Department of Energy, 2020), (Lstibůrek & Carmody, 2012)
		B.7	Climate responsive insulation	Climate-responsive insulation plays a pivotal role in enhancing a building's adaptability by tailoring insulation solutions to specific climate conditions. Such an approach allows for better control of the indoor environment, leading to several benefits. Climate-responsive insulation optimizes energy efficiency by adapting insulation strategies to local climate patterns, reducing the building's reliance on mechanical heating and cooling systems and aligning with evolving energy efficiency regulations. It fosters year-round comfort by mitigating temperature extremes, ensuring the building remains adaptable to seasonal changes and variable weather conditions .	(International Energy Agency, 2015), (Olesen et al., 2019)
		B.8	Air sealing	Air sealing in insulation significantly contributes to a building's adaptability by enhancing energy efficiency, indoor comfort, and overall building performance. By preventing unwanted drafts and air leaks, air sealing minimizes heat loss in cold weather and heat gain in hot weather, reducing heating and cooling costs and ensuring the building meets evolving energy efficiency standards .	https://www.energy.gov/energysaver/weatherize/air-sealing-your-home

Figure 29 sub-criteria and criteria regarded to service layer of adaptable building

Services	C. Energy	C.1	Optimise material use for heating / cooling	materials with good thermal properties help maintain indoor comfort, ensuring that the building remains adaptable to varying climate conditions and occupant needs. By optimizing material selection, a building can achieve better resilience and long-term adaptability in response to climate change and market demands. Optimizing material use for heating and cooling in a building is a fundamental strategy for enhancing its adaptability. By selecting and using materials with high thermal mass or insulation properties strategically, the building can efficiently store and release heat, reducing the need for mechanical heating and cooling systems. This approach not only lowers energy consumption and operational costs but also aligns with evolving energy efficiency regulations, making the building adaptable to changing standards.	Santamouris, M. (2013). Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy, 103, 682-703.
		C.2	natural ventilation	Natural ventilation can significantly contribute to the adaptability of a building in multiple ways. Firstly, it enhances energy efficiency by reducing the reliance on mechanical HVAC systems, lowering energy consumption and operating costs, and ensuring compliance with evolving energy efficiency standards. Secondly, natural ventilation supports indoor air quality, providing occupants with fresh air and reducing the risk of indoor pollutants and health-related issues, which is crucial for the adaptability of the building in terms of occupant well-being.	(Awbi, 2003), (Nicol et al., 2012)
		C.3	local cooling	Local cooling strategies, such as shading devices, reflective roof materials, and natural ventilation, can significantly contribute to a building's adaptability. They reduce the reliance on energy-intensive air conditioning systems, enhancing energy efficiency and making the building more adaptable to changing energy regulations and cost fluctuations.	Santamouris, M. (2001). Energy and Climate in the Urban Built Environment. James & James Science Publishers.
		C.4	local energy/heat storage	Local energy or heat storage systems can significantly contribute to the adaptability of a building by enhancing energy efficiency, resilience, and sustainability. These systems store excess energy, such as solar or off-peak electricity, and surplus heat when available, making it readily accessible during peak demand or inclement weather, thereby reducing energy costs and grid reliance. This increases the building's adaptability by providing a reliable source of energy, even in adverse conditions or power outages. Moreover, heat storage systems, like thermal mass, can help maintain comfortable indoor temperatures by slowly releasing stored heat, reducing the need for mechanical heating and cooling systems and ensuring adaptability to varying climates.	(Ghatikar et al., 2012), (Yohanis & Norton, 2009)
		C.5	Optimize color use to heat absorption/reflection	Optimizing color use in building materials can significantly contribute to a building's adaptability. Light-colored, reflective surfaces on roofs and walls can reduce heat absorption during hot weather, keeping indoor temperatures lower and reducing the need for air conditioning, which enhances energy efficiency .	Santamouris, M. (2013). Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy, 103, 682-703
		C.6 SKIN	Eliminate Energy losses through façade	Eliminating energy losses through the building's façade is a critical factor contributing to the adaptability of the structure. A well-insulated and airtight façade prevents heat loss during colder months and heat gain during warmer periods, resulting in reduced energy consumption and lower operating costs.	Carmody et al., 2004
		C.7SKIN	Insulation and acoustics system	An effective insulation and acoustics system can significantly contribute to the adaptability of a building. Insulation not only enhances energy efficiency by minimizing heat transfer but also improves thermal comfort, reducing the need for mechanical heating and cooling systems and aligning with evolving energy efficiency standards. it ensures consistent indoor temperatures, making the building adaptable to diverse climates and seasons. Simultaneously, an acoustics system controls noise levels, promoting a quieter and more productive indoor environment, which is crucial for occupant well-being and adaptability.	(Sundberg et al., 2013)
		C.8 SKIN	Glazing and shading	Glazing and shading strategies play a vital role in enhancing the adaptability of a building. High-performance glazing materials, such as low-emissivity (Low-E) windows, can significantly improve energy efficiency by reducing heat transfer, enhancing occupant comfort, and complying with evolving energy regulations	(U.S. Department of Energy, 2020)
		C.9	Orientation of the building	The orientation of a building is a crucial design element that can significantly contribute to its adaptability. Proper orientation takes advantage of the building's natural surroundings and climatic conditions to enhance energy efficiency and occupant comfort. For instance, orienting a building to maximize south-facing windows can harness passive solar heating during the winter, reducing the need for artificial heating and aligning with energy-efficient practices	(Oswald et al., 2016)
		C.10	Maintenance access	Maintenance access is a critical aspect of building design that greatly contributes to adaptability. Adequate and well-planned maintenance access ensures that routine upkeep and necessary repairs can be carried out efficiently and safely. This reduces maintenance downtime and costs, making the building more adaptable to the changing needs of occupants and evolving regulatory requirements .Additionally, easy access for maintenance personnel promotes the long-term sustainability and resilience of the building, allowing it to function optimally under various conditions and adapt to unforeseen challenges.	(Kong & Lam, 2013), Meier, A. K., Pfaffenbichler, P. C., Scholl, P. C., & Grunenberg, A. (2015). Adaptability as a measure for sustainability in planning and construction. In Proc., Int'l. Conf. on
		C.11	Scalability	Scalability in building design refers to the capacity to easily expand, shrink, or modify the structure to accommodate changing needs over time. It significantly contributes to a building's adaptability by allowing it to evolve in response to varying requirements without extensive reconstruction. This adaptability ensures the building can be repurposed for different functions, accommodate new technologies, or adjust to shifts in occupancy or use patterns .Scalable designs, such as modular construction techniques, support cost-effective expansions or modifications, reducing the financial burden of adapting to changing demands .	Gann, D. M., Salter, A. J., & Whyte, J. K. (2018). Design innovation in complex infrastructures: Lessons from Crossrail. California Management Review, 61(2), 38-59, Milani Alfredo, S. A., Sousa, J. P., Guedes, J., & Costa, J. C. (2019)
		C.12	Remote control and automation	Remote control and automation systems significantly enhance a building's adaptability by providing real-time monitoring, control, and adjustment of various building functions, such as heating, cooling, lighting, and security, from a distance. These technologies allow building operators to respond swiftly to changing conditions and occupant needs, optimizing energy efficiency and comfort. remote control and automation play a pivotal role in making a building adaptable to dynamic environmental, economic, and technological changes.	(Hassan et al., 2019) ,(Rinaldi et al., 2015)
		C.13	Energy storage	Energy storage systems in buildings can significantly contribute to adaptability by enhancing energy management and resilience. These systems store excess energy, such as electricity generated from renewable sources, for use during peak demand or power outages, reducing grid dependence and lowering energy costs. energy storage enhances a building's adaptability by optimizing energy use, supporting sustainability goals, and providing resilience in challenging conditions.	Lai, J., Liu, C., Wu, Y., & Kang, L. (2015).

Figure 30 sub-criteria and criteria regarded to service layer of adaptable building

Services	D. Water consumption	D.1	Waste water treatment and local reuse	Wastewater treatment and local reuse systems in buildings can significantly enhance adaptability by promoting sustainability, reducing resource dependency, and fostering resilience. These systems treat and recycle wastewater for non-potable uses such as irrigation, flushing, or cooling, reducing the demand on freshwater sources and lowering utility costs .	(Tchobanoglous et al., 2014)
		D.2	Local water collection	Local water collection systems, such as rainwater harvesting and stormwater management, play a vital role in enhancing the adaptability of a building. These systems allow for the collection and storage of rainwater or storm runoff from the building's immediate environment, providing an alternative and sustainable water source for various non-potable uses within the building, including irrigation, toilet flushing, and cooling.	Bao, X., Fang, J., Yang, L., & Xie, X. (2018)
		D.3	Grey water recycling	By reducing the building's reliance on centralized water supply networks, local water collection promotes resource efficiency and lowers utility costs, making the building more adaptable to changing economic conditions and water scarcity issues. Moreover, in times of water supply disruptions or emergencies, these systems ensure a continuous water source, enhancing the building's resilience and adaptability.	(Fletcher et al., 2019)
		D.4	Rainwater harvesting	Local water collection systems, such as rainwater harvesting and stormwater management, play a vital role in enhancing the adaptability of a building. These systems allow for the collection and storage of rainwater or storm runoff from the building's immediate environment, providing an alternative and sustainable water source for various non-potable uses within the building, including irrigation, toilet flushing, and cooling. By reducing the building's reliance on centralized water supply networks, local water collection promotes resource efficiency and lowers utility costs, making the building more adaptable to changing economic conditions and water scarcity issues .	(Bao et al., 2018), (Fletcher et al., 2019),
		D.5	Water metering	Water metering in buildings can significantly enhance their adaptability by promoting water efficiency and conservation. By accurately measuring and monitoring water usage, building managers and occupants can gain valuable insights into their water consumption patterns and identify areas where water can be saved. This information can inform the implementation of water-saving technologies and practices, such as low-flow fixtures, leak detection systems, and rainwater harvesting, which can help reduce water consumption and lower utility bills. Furthermore, in the context of climate change and fluctuating water availability, water metering provides essential data to adapt and optimize water management strategies, ensuring that buildings can efficiently use water resources while minimizing their environmental impact. References to support this concept could include studies on the benefits of water metering in buildings, water conservation strategies in green building certifications like LEED, and the importance of water efficiency in sustainable building design.	(e.g., U.S. Green Building Council, World Green Building Council)
		D.6	Smart water control	Smart water control systems play a crucial role in enhancing a building's adaptability by providing real-time monitoring and control of water usage. These systems incorporate advanced sensors and technology to track water consumption patterns, detect leaks, and optimize water distribution within the building. By analyzing data and responding to real-time information, smart water control systems can automatically adjust water flow and temperature, leading to more efficient water use and reduced waste. This adaptability not only promotes sustainability but also enhances occupant comfort and safety.	International WELL Building Institute and the Smart Buildings Institute
		D.7	Plumping accessibility	Plumbing accessibility in buildings is a vital aspect of adaptability, ensuring that maintenance and upgrades can be conducted efficiently and cost-effectively over time. Properly designed plumbing systems with easy-to-access components, such as shutoff valves and service points, facilitate repairs, renovations, and the integration of new technologies like water-efficient fixtures or renewable water sources. This accessibility reduces downtime and disruption to building occupants during maintenance activities, ultimately contributing to the building's long-term sustainability and adaptability.	(EPA, 2017) U.S. Environmental Protection Agency (EPA) titled "WaterSense at Work

Figure 31 sub-criteria and criteria regarded to service layer of adaptable building

Services	Lightning				
		E.1	Using natural ligh for interior spaces	The utilization of natural light for interior spaces is a key element in enhancing a building's adaptability and sustainability. By incorporating well-planned daylighting strategies, buildings can significantly reduce their reliance on artificial lighting, leading to substantial energy savings and lower operating costs over time. Moreover, natural light promotes a healthier and more productive indoor environment by providing adequate illumination, reducing eyestrain, and regulating circadian rhythms.	Boubekri et al. (2014)
		E.2	Optimize color use to light absorption/reflection	Optimizing color use in a building's design, particularly in surfaces and materials, can significantly contribute to its adaptability. The selection of colors that enhance light absorption or reflection can have a substantial impact on energy efficiency and occupant comfort. Light-colored surfaces, such as walls, ceilings, and floors, can reflect natural and artificial light, reducing the need for additional lighting and lowering energy consumption. Conversely, dark-colored surfaces can absorb heat and contribute to passive solar heating in colder climates. Research by the Lawrence Berkeley National Laboratory, like the report "Cool Colors: Reducing Energy Costs through Cool Roof Coatings," demonstrates how cool colors and reflective materials can mitigate heat gain in buildings and lower cooling costs.	Akbari, H., Bretz, S., Kurn, D. (2000)
		E.3	Location and size/shape of daylight facilities	The location and size/shape of daylight facilities are pivotal factors in enhancing a building's adaptability. Thoughtfully designed windows, skylights, and other daylighting features can optimize the utilization of natural light, thereby reducing the dependence on artificial lighting and lowering energy consumption. Properly placed openings can also maximize the distribution of daylight throughout the interior spaces, promoting a more comfortable and productive environment for occupants. Additionally, the size and shape of these facilities should be tailored to suit the building's specific needs, allowing for adaptable control over the amount of daylight entering the space.	https://www.pge.com/includes/docs/pdfs/shared/edusafety/training/pec/daylighting/heschong_mahone_daylighting_in_schools_report.pdf
		E.4	Lighting control	Lighting control systems play a crucial role in enhancing a building's adaptability by providing dynamic and efficient management of artificial lighting. These systems enable users to adjust lighting levels based on occupancy, natural light availability, and time of day, thus reducing energy consumption and extending the lifespan of lighting fixtures. The adaptability of a building is further enhanced through the integration of sensors and automation, which can respond to changing environmental conditions.	https://www.energy.gov/sites/prod/files/2014/06/f16/advanced_controls.pdf
		E.5	Smart lightning system	Smart lighting systems offer a transformative contribution to a building's adaptability by providing dynamic and responsive control of artificial lighting. These systems integrate sensors, automation, and network connectivity to optimize lighting based on occupancy, daylight levels, and user preferences. Smart lighting can adapt to changing conditions, ensuring that the right amount of light is delivered where and when it is needed, thereby reducing energy consumption and enhancing occupant comfort	Li, D., Yang, X., Li, H., & Zhang, C. (2018)
		E.6	Lightning zoning	Lighting zoning, which involves dividing a building's lighting system into distinct zones that can be controlled independently, is a significant contributor to a building's adaptability. This approach allows occupants or building managers to tailor lighting levels to specific areas or tasks, responding to changing needs and preferences. By using zoning in conjunction with occupancy sensors and natural light sensors, energy consumption can be optimized by only illuminating areas in use and dimming or turning off lights in unoccupied or naturally lit zones.	Kim, M. S., & Kim, J. T. (2018)
		E.7	Daylight harvesting	Daylight harvesting is a sustainable design strategy that can significantly enhance the adaptability of a building. By integrating sensors and automated systems to optimize the use of natural light, buildings can reduce their reliance on artificial lighting and minimize energy consumption, which is crucial for adapting to changing environmental and economic conditions.	(Nabil and Mardaljevic, 2006)
		E.8	Emergency Lightning	emergency lighting ensures that occupants can safely evacuate in the event of a power outage or other emergencies, thereby increasing the building's resilience to unforeseen disruptions. Emergency lightning Additionally, modern emergency lighting systems are designed with energy-efficient LED technology and can be integrated with building automation systems, making them adaptable to changing energy requirements and regulations.	S. Lock and S. S. Khan (2019)

Figure 32 sub-criteria and criteria regarded to service layer of adaptable building

Services	Air Quality	F.1	Fine dust/ Exhaust system	A fine dust or exhaust system is crucial for improving the adaptability of a building, as it plays a pivotal role in maintaining indoor air quality and overall occupant health. Fine dust, also known as particulate matter (PM), can originate from various sources, including industrial emissions, vehicular exhaust, and natural sources like dust and pollen. Without an efficient exhaust system, fine dust can infiltrate indoor spaces, leading to a range of health issues such as respiratory problems and allergies. Proper ventilation and exhaust systems help remove fine dust and pollutants from the indoor environment, ensuring that occupants breathe clean and healthy air. This is especially important in urban areas where pollution levels can be elevated. Additionally, an effective exhaust system can enhance thermal comfort by regulating temperature and humidity levels, which is vital for occupant well-being and productivity.	https://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf
		F.2	Natural ventilation	Natural ventilation is essential for improving the adaptability of a building as it promotes energy efficiency, occupant comfort, and environmental sustainability. By harnessing natural airflow through openings like windows and vents, buildings can reduce the reliance on mechanical ventilation systems, leading to energy savings and lower operational costs. Moreover, natural ventilation enhances indoor air quality by constantly replenishing the air and expelling pollutants, thereby creating a healthier and more comfortable living or working environment.	Givoni, B. (1998). Climate Considerations in Building and Urban Design. Van Nostrand Reinhold. Awbi, H. B. (2003). Ventilation of Buildings. Taylor & Francis.
		F.3	Green lungs	Green lungs contribute to thermal comfort by providing shade and reducing the urban heat island effect, mitigating the adverse effects of extreme temperatures on buildings and their occupants. Additionally, green spaces promote biodiversity, reduce noise pollution, and create aesthetically pleasing surroundings, which can increase property values and make the area more desirable for residents and businesses. Green lungs, also known as green spaces or urban greenery, are crucial for improving the adaptability of a building and its surroundings. These green areas, which can include parks, gardens, and trees, provide a multitude of benefits. They act as natural air purifiers, absorbing pollutants and enhancing air quality, making the environment healthier for building occupants and improving overall well-being.	Ulrich, R. S. (1984). View through a window may influence recovery from surgery. Science, 224(4647), 420-421. Kabisch, N., & Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. Landscape and Urban Planning, 122, 129-
		F.4	Façade windows to be opened	Openable façade windows are essential for improving the adaptability of a building by providing several key advantages: Natural Ventilation, Thermal Comfort, Connection to Outdoors, Emergency Egress.	ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers): ASHRAE provides guidelines and standards related to building ventilation and indoor air quality, which often
		F.5	Wellness certification	Wellness certifications, such as the WELL Building Standard or Fitwel, provide guidelines and benchmarks for creating spaces that prioritize occupant well-being. These certifications consider factors like indoor air quality, access to natural light, ergonomic design, and physical activity promotion. By adhering to wellness standards, buildings become adaptable to evolving health and wellness trends, making them more appealing and productive spaces for occupants. Research has shown that wellness-certified buildings can lead to improved occupant health, productivity, and overall satisfaction, underscoring the significance of such certifications in enhancing building adaptability.	International WELL Building Institute. (n.d.). The WELL Building Standard. Retrieved from https://www.wellcertified.com/
		F.6	Maintenance protocols	Maintenance protocols play a crucial role in enhancing the adaptability of buildings by ensuring their long-term functionality and resilience. Regular and proactive maintenance, guided by established protocols, can extend the lifespan of building systems and components, thereby reducing the need for costly renovations or replacements. This not only conserves resources but also allows buildings to evolve more efficiently to meet changing needs. For instance, a well-maintained HVAC system can be upgraded with advanced, energy-efficient technology, contributing to improved sustainability and occupant comfort. Additionally, maintenance protocols that include inspections and repairs for weatherproofing and structural integrity can help buildings withstand environmental challenges and adapt to the effects of climate change. As a result, buildings that prioritize effective maintenance protocols can better accommodate evolving requirements, ensuring their continued functionality and relevance.	Ostrowski, P., & Teichman, L. (2018). Building Operations and Maintenance: A New Model for Increasing Energy Efficiency in Existing Buildings. International Journal of High-Rise Buildings, 7(3), 185-193. doi:10.21022/IJHRB.2018.7.3.185
		F.7	Indoor plants	Indoor plants play a significant role in enhancing the adaptability of buildings by contributing to a healthier and more comfortable indoor environment. Research has shown that the presence of indoor plants can improve indoor air quality by absorbing pollutants and releasing oxygen, which is particularly crucial in tightly sealed modern buildings. Moreover, plants can regulate humidity levels, reducing the risk of dry indoor air that can lead to discomfort and health issues. The aesthetic and psychological benefits of indoor greenery, including stress reduction and enhanced productivity, can also contribute to occupant well-being and adaptability in the workplace. Furthermore, the strategic placement of plants within a building can provide natural zoning, aiding in spatial adaptability as areas can be easily reconfigured to accommodate changing needs.	Lohr, V. I., & Pearson-Mims, C. H. (1996). Particulate Matter Accumulation on Horizontal Surfaces in Interiors: Influence of Foliage Plants. Atmospheric Environment, 30(14), 2565-2568. doi:10.1016/1352-2310(95)00324-3
		F.8	Ventilation system design	Ventilation system design is a cornerstone in enhancing the adaptability of buildings, especially in the context of evolving environmental and health considerations. Well-designed ventilation systems not only ensure a continuous supply of fresh outdoor air but also offer the flexibility to adjust airflow rates and air quality measures in response to changing needs. Advanced systems incorporate heat recovery, demand-controlled ventilation, and air purification technologies, contributing to energy efficiency and occupant comfort. This adaptability is particularly important in the wake of health crises, such as the COVID-19 pandemic, where ventilation systems can be optimized to enhance indoor air quality and reduce disease transmission risks. A study by Awbi and Howarth (2016) highlights the significance of ventilation system design in optimizing indoor air quality and thermal comfort, thus contributing to the overall adaptability and well-being of building occupants.	Awbi, H. B., & Howarth, C. J. (2016). Predicting Indoor Air Quality and Comfort in Buildings: Modeling and Simulation. Building and Environment, 100, 120-133. doi:10.1016/j.buildenv.2016.02.019
		F.9	Air filteration	Air filtration systems are integral to enhancing the adaptability of buildings by promoting a healthier and more resilient indoor environment. These systems, equipped with high-efficiency filters, can effectively remove airborne contaminants, including allergens, particulate matter, and pathogens, which is crucial for occupant health and well-being. With the increasing emphasis on indoor air quality and the need to adapt to evolving health concerns, such as airborne viruses, advanced air filtration systems can be integrated or upgraded in buildings to address emerging threats. A study by Wargocki and Wyon (2017) underscores the importance of air filtration in reducing indoor air pollution and its positive impact on occupants' cognitive performance and overall comfort, highlighting how filtration systems contribute to the adaptability and future-proofing of buildings.	Wargocki, P., & Wyon, D. P. (2017). Ten Questions About People's Responses to Ventilation. Building and Environment, 123, 106-116. doi:10.1016/j.buildenv.2017.07.022

Figure 33 sub-criteria and criteria regarded to service layer of adaptable building

Structure	Load bearing	G.1.1	Fire resistant load bearing	Fire-resistant load-bearing structures are paramount in enhancing the adaptability of buildings, as they bolster the load-bearing capacity of a structure while ensuring its safety in the event of a fire. By incorporating fire-resistant materials and design features, buildings can withstand the intense heat and stress of a fire, providing crucial time for evacuation and emergency response. This not only safeguards lives and property but also reduces the need for extensive structural repairs or reconstruction after a fire incident. A study by Abbasi et al. (2016) emphasizes the significance of fire-resistant materials and design strategies in maintaining structural integrity, enhancing building resilience, and facilitating adaptability to various challenges, including fire events.	Abbasi, T., Abbasi, S. A., & Das, S. (2016). Structural Materials for the Transportation Infrastructure: Responding to the Challenge. CRC Press.
		G.1.2	Extendible buildig/ Vertical unit	Extendible building systems, including vertical units and modular structures, play a pivotal role in enhancing the adaptability of buildings by offering scalable load-bearing capacity. These systems allow for the addition of extra floors or units without compromising structural integrity, thus accommodating evolving space requirements. The capability to vertically expand a building provides a sustainable and cost-effective way to adapt to changing needs over time, such as increasing occupancy, additional office spaces, or residential units. A study by Hua et al. (2020) underscores the versatility and load-bearing capacity benefits of modular construction, demonstrating its potential to enhance building adaptability and responsiveness to dynamic demands.	Hua, Y., Cui, S., Liu, C., & Li, X. (2020). A Study on the Design and Construction of Modular Buildings. Journal of Construction Engineering and Management, 146(3), 04019116. doi:10.1061/(ASCE)CO.1943-7862.0001774.
		G.1.3	Shape of columns	The shape of columns in a building can significantly contribute to enhancing its adaptability by improving load-bearing capacity and spatial flexibility. Innovative column designs, such as reinforced concrete or steel composite shapes, can distribute loads more efficiently and support larger spans, allowing for the creation of open and adaptable interior spaces. These columns can also be tailored to accommodate future structural modifications or additions, reducing the constraints of traditional column designs on interior layouts. A study by Hambly (1998) emphasizes the importance of column design in modern architectural practice, highlighting how innovative column shapes enhance structural adaptability, thus enabling buildings to evolve and meet changing functional requirements.	Hambly, E. C. (1998). The Evolution of Long-Span, Column-Supported Structures in the 20th Century. The Structural Engineer, 76(15), 261-267.
		G.14	Load bearing foundation for extending stories	Utilizing a load-bearing foundation for extending stories is a pivotal strategy in enhancing the adaptability of buildings, as it significantly bolsters their load-bearing capacity. A well-designed foundation can safely support additional stories or vertical expansions, accommodating future growth or changing requirements without compromising structural integrity. By distributing loads efficiently and ensuring stability, load-bearing foundations enable buildings to adapt to increased live loads, seismic forces, or the addition of new floors, all while maintaining safety and performance standards. A study by Elghazouli et al. (2019) underscores the importance of robust foundations in modern construction, emphasizing how they enhance load-bearing capacity and contribute to the adaptability and resilience of buildings in the face of dynamic demands.	Elghazouli, A., & Yeomans, J. S. (2019). Seismic Design and Assessment of Building Foundations: The Case for Eurocode 8. Bulletin of Earthquake Engineering, 17(5), 2149-2169. doi:10.1007/s10518-018-00508-3.
		G.1.5	Column and Beam Spacing	Column and beam spacing plays a crucial role in enhancing the adaptability of a building. By optimizing the spacing between these structural elements, architects and engineers can significantly influence the load-bearing capacity and flexibility of a structure. Research by Ashwini K. Sinha and S. K. Dubey in their paper "Effect of Different Column and Beam Spacing on the Seismic Behavior of RC Framed Structures" highlights that appropriate spacing allows for efficient distribution of loads, thereby improving the building's capacity to withstand various forces, including seismic activity. Moreover, well-planned spacing permits more versatile interior layouts, enabling easy reconfiguration of spaces to accommodate changing needs and uses. This adaptability is particularly important in contemporary urban environments, where buildings must respond to evolving functional requirements without the need for costly structural modifications, making them more sustainable and economically viable over time.	Ashwini K. Sinha and S. K
		G.1.6	Assembly and dissassembly equipment	The integration of assembly and disassembly equipment within a building's design can significantly enhance its adaptability. Underscores that such equipment enables the efficient construction and deconstruction of building components, thereby improving load-bearing capacity adaptability. Prefabricated and modular construction methods, supported by assembly equipment, allow for rapid assembly and disassembly, facilitating quick alterations or expansions to meet changing requirements. This adaptability is particularly valuable in scenarios where buildings must respond to fluctuating space demands, fostering sustainability by minimizing waste and resource consumption over the building's lifecycle. By integrating assembly and disassembly mechanisms, buildings become more flexible, cost-effective, and eco-friendly in the face of evolving needs and constraints.	"Integration of Assembly and Disassembly Processes for Sustainable Building" (2018)
	Foundation design	G.2.1	Structural grid	The strategic design of a structural grid in the foundation of a building can significantly enhance its adaptability. Foundation's structural grid serves as the backbone of the entire building, determining its load-bearing capacity and flexibility. By carefully configuring the grid layout, architects and engineers can accommodate various functional requirements and potential future modifications. A well-designed structural grid provides the adaptability needed to support changes in interior layouts, additional floors, or the incorporation of new technologies without compromising the building's stability. This adaptability not only ensures the building's longevity but also reduces the need for extensive and costly structural alterations, making it a more sustainable and economically viable solution over time.	"Optimal Design of Structural Grid Systems for Sustainable Building Construction" (2019)
		G.2.2	Building Codes and Regulations	Building codes and regulations play a vital role in enhancing the adaptability of a building, particularly in foundation design. As emphasized in "Building Codes and the Design of Timber Structures" by D. R. Rammer (2017), these codes provide essential guidelines and standards that ensure the safety, resilience, and longevity of structures. By adhering to established building codes and regulations, architects and engineers can design foundations with a strong emphasis on load-bearing capacity and stability, enabling buildings to withstand a wide range of conditions and adapt to changing needs over time. These codes often incorporate provisions for seismic resistance, environmental sustainability, and safety, contributing to the long-term viability and adaptability of the structure. Additionally, compliance with building codes ensures that a building's foundation is constructed to meet accepted industry standards, reducing the risk of structural failures and costly retrofits in the future.	"Building Codes and the Design of Timber Structures" by D. R. Rammer (2017)

Figure 34 sub-criteria and criteria regarded to structural layer of adaptable building

Site	H.1	Expandable site	When a building is situated on an expandable site, it allows for easy expansion or modification of the structure as required, without the constraints of limited space or land. This adaptability enables the building to evolve along with its intended functions, whether it's for residential, commercial, or institutional purposes. An expandable site offers the flexibility to add new wings, additional floors, or supplementary structures, making the building resilient and adaptable to a wide range of potential uses and growth scenarios over time, ultimately ensuring its long-term relevance and sustainability.	"Flexible Housing: A Critical Review" (2017)
	H.2	Multifunctional site	When a building is situated on a multifunctional site, it gains versatility and resilience, capable of accommodating various activities and uses. Such sites, which may include mixed-use developments, plazas, or community centers, provide opportunities for diverse programming and events, ensuring that the building remains a dynamic and adaptable hub within the community. This adaptability not only allows the building to meet changing needs but also fosters community engagement and vitality, contributing to its long-term sustainability and relevance as it continues to serve as a catalyst for various activities and interactions in the area.	"Cities for People" (2010)
	H.3	Safety and security	A secure and safe environment is fundamental to a building's functionality and long-term viability. When a site is well-protected and secure, it not only safeguards the building, its occupants, and assets but also ensures that it can adapt effectively to unforeseen challenges and changing circumstances. This security enables the building to continue functioning during crises or emergencies, supporting its occupants and maintaining essential services. In turn, this contributes to the long-term adaptability and sustainability of the building, as it remains a reliable and secure asset in the face of evolving threats and uncertainties.	"A Framework for the Integration of Safety and Sustainability Assessment in Building Design" (2017)
	H.4	Quality of mobility	Underscores that accessible and well-designed transportation infrastructure contributes to a building's adaptability. When a site offers excellent mobility options such as efficient public transit, pedestrian-friendly pathways, and bike lanes, it reduces dependency on individual vehicles and promotes sustainable transportation modes. This not only reduces traffic congestion and environmental impact but also ensures that the building remains accessible and functional in the face of changing transportation trends and preferences. High-quality mobility options allow the building's occupants and users to easily reach it, fostering its continued relevance and adaptability within the community and urban context.	Cervero, R., & Murakami, J. (2010)
	H.5	Natural landscape	When a building is situated within a site that embraces natural features such as green spaces, trees, water bodies, and wildlife habitats, it fosters a deeper connection with nature. These natural elements not only enhance the aesthetic appeal of the surroundings but also contribute to the well-being of building occupants by providing opportunities for relaxation and recreation. Moreover, a site with natural landscape features can adapt to changing environmental conditions and serve as a resilient buffer against climate-related challenges, such as extreme heat or flooding. By integrating nature into the site design, a building becomes more adaptable and sustainable, as it benefits from the ecological services and inherent flexibility that natural landscapes offer, ultimately ensuring its long-term relevance and resilience in the face of evolving urban dynamics and environmental concerns.	Beatley, T. (2011) in his book "Biophilic Cities
	H.6	Walkability	walkable neighborhoods with pedestrian-friendly infrastructure not only promote physical health but also contribute to the adaptability and sustainability of a building. When a building is located in a walkable area with well-designed sidewalks, crosswalks, and easy access to amenities, it reduces reliance on automobiles and encourages active transportation modes. This not only mitigates traffic congestion and pollution but also ensures that the building remains easily accessible and functional as transportation preferences evolve. Moreover, walkability fosters a sense of community, supporting local businesses and social interactions, which in turn enhances the building's long-term adaptability and relevance within a vibrant and resilient neighborhood.	Frank and Engelke ''Multiple Impacts of the Built Environment on Public Health''2001
	H.7	Distances to the entrance	When a building is designed with shorter and more accessible paths to its entrances, it ensures that it remains adaptable and inclusive. Shorter distances and easy access reduce barriers for individuals with mobility challenges and accommodate a wider range of users. This adaptability is especially crucial in emergency situations, as quick and accessible entrances can ensure the safety of all occupants. By prioritizing shorter distances to entrances, a building becomes more versatile, responsive to changing needs, and compliant with universal design principles, ultimately enhancing its long-term adaptability and usability for a diverse user base.	Steinfeld and Maisel in their book "Universal Design: Creating Inclusive Environments" (2012)
	H.8	Diversity	When a building is situated within an environment that features a variety of green spaces, water features, public art, and mixed land uses, it becomes more adaptable and resilient. A diverse environment not only enhances the aesthetic appeal but also contributes to the overall well-being of building occupants, offering different opportunities for recreation, relaxation, and social interaction. Moreover, a site with diverse elements is better equipped to adapt to changing climate conditions, urban dynamics, and community needs, ensuring that the building remains relevant and valuable over time. The integration of diversity into the environment and site design fosters adaptability and sustainability, making the building a more resilient and vibrant asset within its surroundings.	Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas" , Pickett et al.(2001)
	H.9	Cultural and heritage preservation	Cultural and heritage preservation within the environment and site can significantly enhance the adaptability of a building. Research by Jokilehto, J. (2006) in "Considerations on Authenticity and Integrity in World Heritage Context" underscores the importance of recognizing and safeguarding cultural and historical elements within the built environment. When a site is dedicated to the preservation of cultural and heritage assets, it fosters a sense of identity, continuity, and community attachment. This commitment to cultural preservation not only enriches the building's surroundings but also ensures that the building itself becomes a part of a broader narrative, deeply rooted in its historical context. This connection with heritage encourages responsible stewardship and adaptive reuse of buildings, contributing to their long-term adaptability. By integrating cultural and heritage preservation, a building becomes not just a functional space but a testament to the past, which inspires a sense of responsibility and adaptability, ensuring its continued relevance and value to future generations.	Jokilehto, J. (2006)

Figure 35 criteria regarded to site of adaptable building

Space plan	I.1.1	Flow and Circulation	Good space planning facilitates smooth movement through a space. This includes considering the placement of doors, corridors, and furniture to create a logical path of movement.	
	I.1.2	Material Choices	This includes determining finishes for work surfaces and humid zones, flooring in regard to expected transit and visual perception, as well as colors and materials for walls and decorations	Bechthold, Martin, and James C. Weaver. "Materials science and architecture." Nature Reviews
	I.1.3	Human-Centric Design	The design should fulfill psychological needs and promote good mental and physical health	https://blog.dormakaba.com/ https://www.interaction-design.org/
	I.2.1	Ease of Assembly and Disassembly	The design should facilitate easy assembly and disassembly, minimizing the need for specialized tools or skills. This often involves the use of bolted or interlocking connections instead of welded or permanent joints. Ease of assembly and disassembly enhances a building's adaptability by allowing quick reconfiguration to meet changing needs or functions, making it ideal for evolving user requirements. This approach reduces the time and costs associated with structural changes, encouraging more frequent and efficient adaptations. Components designed for easy disassembly can be reused or repurposed, promoting sustainability and reducing environmental impact. The ability to rapidly assemble and disassemble facilitates the use of buildings for temporary needs, such as emergency housing or event spaces. Overall, this flexibility extends the building's lifespan and utility, aligning with sustainable development and efficient resource use. Buildings that can be easily assembled and disassembled tend to have a smaller environmental footprint. According to a study by Gibb and Isack (2003) in "Construction Innovation," the reusability of components in such buildings significantly reduces waste and resource consumption, contributing to sustainability.the design principles that emphasize ease of assembly and disassembly significantly contribute to the adaptability of buildings. They allow for flexibility in use, cost-effective modifications, environmental sustainability, rapid response to changing needs, and the integration of new technologies. These aspects are crucial in addressing the dynamic requirements of modern buildings.	Gibb and Isack (2003), Thormark (2002) , "Design in Modular Construction" (2014)
	I.2.2	Ventilation system design	Modern ventilation systems are designed to be energy-efficient, often incorporating elements of sustainable design like natural ventilation. This makes the building more adaptable to changes in energy availability and environmental regulations. A well-designed ventilation system can quickly adapt to changes in indoor air quality requirements, which is essential for occupant health and productivity. The integration of smart technology in ventilation systems allows for real-time monitoring and adjustment, enhancing the building's ability to adapt to changing conditions. Ventilation systems designed to cope with a range of climatic conditions make buildings more resilient and adaptable to climate change.	Zhang and Barrett in a 2021 study published in the "International Journal of Environmental Research and Public Health," effective ventilation is key to adapting to varying indoor air quality needs. A 2019 article by Smith and Kelsey in the "Journal of Sustainable Architecture" highlights the link between energy-efficient ventilation and long-term building adaptability.
	I.2.3	Modular Design	The building should be designed in modules or sections that can be easily assembled and disassembled. This includes standardized sizes and interfaces for components.Modular design significantly enhances the adaptability of buildings by allowing for easy reconfiguration. Each module can be designed as a self-contained unit, enabling quick and efficient changes to the building's layout or function without major structural alterations. This flexibility is particularly beneficial in responding to evolving space requirements, changing user needs, or technological advancements. Modular buildings can also adapt to different sites and environments since modules can be added, removed, or rearranged with minimal disruption. Additionally, this approach supports sustainability by facilitating reuse and recycling of modules, reducing waste and resource consumption over the building's lifecycle.	Arundel, et al., in their 2020 study

Figure 36 Criteria regarded space plan of adaptable building

4.3.4. Contextual contingencies framework

Israelsson and Hansson (2009) argued that adaptability in buildings is commonly understood in a limited way, focusing mainly on physical attributes. However, the broader scenario involving the design, building, and use of structures suggests that adaptability involves more than just the physical components. The capacity of buildings to adapt, as well as the ways they are adopted and altered, is influenced by a complex mix of social, economic, and political factors. These factors are known as 'contextual contingencies', which means that the specific context dictates how various elements can either enhance or hinder adaptability. This concept is further explored in a table in the second part of the proposed framework, and it is not about the physical criteria of the adaptable building.

Contextual contigencies

Layer	Number	Criteria	Explanation	References
Social	J.1	Privacy	Privacy considerations are integral to enhancing the adaptability of a building. Research by C. Michael Hall and Kim Peters in their paper "Urban and Community Tourism: Place, Identity, and Culture" (2010) underscores that privacy is a fundamental aspect of human well-being and comfort within a built environment. A building's design that takes privacy into account allows occupants to personalize their spaces and adapt them to changing needs, fostering a sense of ownership and satisfaction. The ability to create private areas within a building, through well-placed partitions, layouts, or sound insulation, enables residents to accommodate diverse activities, such as work, leisure, or social interactions, without disturbing others. This adaptability supports the building's functionality over time, making it more resilient to evolving lifestyles and preferences, ultimately contributing to its long-term sustainability and relevance.	Urban and Community Tourism: Place, Identity, and Culture" (2010)
	J.2	Occupants engagements	Occupant engagement is a pivotal factor in enhancing the adaptability of a building. As highlighted in the research by Itard, L., Visscher, H., & Hoes, A. C. (2014) titled "Implementing Building-Related Health Promotion into Practice in Dutch Building Companies," when building occupants actively participate in decisions related to their environment, it fosters a sense of ownership and empowerment. This engagement can lead to more adaptable spaces as occupants have firsthand insights into their evolving needs and preferences. Through surveys, feedback mechanisms, or collaborative design processes, occupants can influence modifications and improvements to the building's layout, amenities, and technologies. This ongoing dialogue between occupants and building management or designers ensures that the building can readily adapt to changing requirements, optimizing its functionality and overall satisfaction, and ultimately contributing to its long-term viability in a dynamic world.	Occupant engagement is a pivotal factor in enhancing the adaptability of a building.
	J.3	Affordability	Affordability is a critical factor in enhancing the adaptability of a building. As emphasized in the research by B. Edwards and L. A. Bin (2007) titled "Flexibility, adaptability and affordability in housing: Some lessons from the United States and Britain," an affordable building design ensures that a wider range of individuals and organizations can access and invest in the property. This inclusivity is key to its adaptability because it allows for a diverse set of occupants or users, each with unique needs and preferences. Affordable buildings often employ modular or flexible design concepts that can be easily adapted or expanded upon, providing cost-effective ways to accommodate changing demands over time. Moreover, affordability ensures that maintenance and retrofitting costs remain manageable, making it more likely that the building will remain functional and relevant for extended periods, contributing to its overall adaptability and sustainability in a dynamic and evolving environment.	B. Edwards and L. A. Bin (2007)
	J.4	Community well-being	Community well-being is intricately linked to the adaptability of a building. Research by Chapman, R. (2009) in "Public health and housing: A review of the evidence" underscores that buildings designed with community well-being in mind contribute to the overall resilience and adaptability of a neighborhood or locality. When a building serves as a hub for community activities, social interactions, and support networks, it fosters a sense of belonging and social cohesion. Such community engagement can lead to collective efforts in adapting and repurposing the building to meet evolving needs and challenges, whether they are related to healthcare, education, or emergency response. In this way, community well-being becomes a driving force behind the adaptability of the building, as the community rallies together to ensure the structure remains relevant, functional, and supportive of its changing requirements over time. This not only benefits the building itself but also enhances the overall sustainability and resilience of the broader community.	Chapman, R. (2009)
	J.5	Cultural preservation	Cultural preservation is a pivotal factor in enhancing the adaptability of a building. Buildings that incorporate elements of cultural heritage and historical significance into their design and function become repositories of collective memory and identity. This preservation of cultural heritage fosters a sense of attachment and responsibility among the community, motivating them to adapt and repurpose the building rather than replace it when facing changing needs or challenges. By maintaining and celebrating cultural elements within the building, its adaptability extends beyond accommodating contemporary uses to honoring and perpetuating the traditions and values of a society, ensuring they remain relevant and integral to the community's identity and sense of place. This dual purpose enhances the building's long-term adaptability and resilience, preserving its cultural significance for future generations.	Intangible Heritage as Metacultural Production" (2004)
	J.6	Youth and Elderly-Friendly	By considering the needs of both youth and elderly populations, a building becomes more versatile and accommodating, ensuring that it can serve a diverse range of occupants effectively. Youth-friendly spaces may incorporate features like recreational areas, study zones, and communal gathering spots, while elderly-friendly elements could include accessible pathways, handrails, and well-designed common areas. This inclusivity not only fosters a sense of community but also ensures that the building can adapt to the changing requirements and demographics of its occupants over time, making it a more resilient and sustainable asset within the neighborhood or community. Creating youth and elderly-friendly areas within a building is pivotal to enhancing its adaptability.	Age-Friendly Environments" (2016)
	J.7	Safety and security	When a building is equipped with robust safety and security features, including fire prevention systems, access controls, surveillance, and emergency response plans, it not only safeguards its occupants and assets but also ensures its adaptability in the face of unforeseen events or changing threats. These measures not only contribute to occupant well-being but also allow the building to withstand and respond effectively to challenges, enabling it to continue serving its intended purpose even in adverse conditions. This, in turn, enhances the building's adaptability and resilience, making it a more valuable asset in an ever-changing world.	A Literature Review" (2018)
	J.8	User centered design	When a building is designed with a deep understanding of its users, it becomes inherently flexible and adaptable, as it can evolve to meet changing requirements and expectations. User-centered design allows for spaces to be tailored to specific functions, ensuring that they remain relevant and efficient over time. Furthermore, ongoing engagement with users allows for continuous improvements and modifications, ensuring that the building remains a responsive and adaptable environment that serves its occupants effectively for the long term.	South African Case Study" (2017)

Economic	K.1	Initial Investment and Design Costs	Adaptable buildings may require a higher initial investment due to the incorporation of flexible design elements, innovative materials, and technology. This upfront cost can be justified by the long-term savings and the potential to avoid costly renovations.	The Costs and Financial Benefits of Green Buildings", a report to California's Sustainable Building Task Force by Kats et al. (2003)
	K.2	Lifecycle Costs	The total cost of owning and operating a building over its lifecycle can be reduced if the structure is adaptable. Buildings that can be easily modified or repurposed can extend their useful life and delay the need for replacement. This can result in significant savings on materials, labor, and waste disposal.	
	K.3	Operational Efficiency	Adaptable buildings often incorporate energy-efficient designs and smart technologies that adapt to usage patterns, reducing operational costs. This includes utilities like electricity, water, and heating/cooling systems, which can adjust based on occupancy or other factors.	"Valuing the Flexibility of Adaptable Buildings: The effect of uncertainty, obsolescence, and life cycle on building valuation" by M. Schwehr and A. Levenson (2004),Flexibility in Building Design: a Real Options Analysis" by G. P. M. De Jong, P. W. de Jong, and J. J. M. Smit (2009)
	K.4	Revenue Opportunities	Adaptable buildings can adapt quickly to market demands, reducing vacancy periods and ensuring a steady revenue flow. Revenue from Multi-Use Configurations: The ability to host multiple functions or businesses simultaneously opens up diverse revenue streams.Adaptable buildings, often aligned with sustainability, can attract investment and funding focused on green initiatives.	
	K.5	Depreciation and Property Value	An adaptable building may depreciate slower than a traditional building because its functionality can be preserved or enhanced over time without substantial structural changes. Additionally, the ability to adapt to market demands can maintain or increase property value.	"Sustainable Building Adaptation: innovations in decision-making" by Sara J. Wilkinson, Hilde Remøy, and Craig Langston (2014), "Building Adaptation" by James Douglas (2006)
	K.6	Resilience to Market Changes	The ability to alter building function in response to market changes means adaptable buildings can potentially maintain higher occupancy rates and, as a result, generate consistent revenue.	Poon (2009) in "Journal of Urban Planning and Development."
	K.7	Job Creation	Adaptable buildings might contribute to economic development by creating a need for specialized design, construction, and retrofitting jobs, which could lead to growth in the local economy.	Green Building Economics: Costs and Benefits" by Kats (2003), The Impact of Control Technology" (2011) , Parnell and Sara (2016) in the "Journal of Architecture Education."
	K.8	Sustainability and Resource Efficiency	The practice of adaptively reusing buildings contributes to sustainability by conserving resources and reducing the need for new construction. Applying lifecycle assessment and circular economy principles in building design ensures that all stages of a building's life are considered for maximum resource efficiency. sustainability and resource efficiency are integral to the adaptability of buildings. By focusing on energy and water efficiency, sustainable materials, modular design, lifecycle assessment, and adaptive reuse, buildings can remain functional and relevant over time, reducing environmental impact and adapting to changing needs and conditions. The referenced academic literature provides detailed insights into these aspects.	2021 study by Röck et al., Conejos et al. (2022)
	K.9	Reduce Retrofitting and renovation costs	Over time, the need for major renovations is lessened in adaptable buildings because they can be easily reconfigured. This flexibility can lead to substantial cost savings.	"Adaptable Futures" research project led by Loughborough University (2007-2010)
	K.10	Risk Mitigation	Adaptable design inherently mitigates risk by allowing building owners to respond to unexpected changes in the environment, economy, or technology, thereby protecting their investment.	"Flexibility in Building Design: General Principles and Infrastructure Investments" by T. M. P. Van Der Voordt (2004)
	K.11	Government Grants and Tax Incentives	Governments may offer tax deductions, credits, or grants for buildings that incorporate adaptable designs, especially if they contribute to sustainability goals.	Tax Incentives and Environmental Policies" by the Organisation for Economic Co-operation and Development (OECD) (2010)
	K.12	Green Financing and Incentives	Proje cts with adaptable designs may qualify for green financing options, such as lower-interest green loans or sustainability grants, due to their potential for environmental benefits.	"Green Finance and Sustainability: Environmentally-Aware Business Models and Technologies" by Z. Zhang (2011)

Evaluation method					
Layers	**Criteria**	**Numbers**	**Sub-criteria**	**Quantitative Questions**	**Qualitative Questions**
Services	Accessibility	A.1	Access to building	Are the entry points to the building adaptable to accommodate different modes of access, such as mobility devices, walkers, or strollers?	
		A.2	Specified acccess for disablers	1. What percentage of the building's total area is wheelchair accessible? 2. How many parking spaces are dedicated to individuals with disabilities, and what is their proportion in relation to the total number of parking spaces?	1. Is there a feedback mechanism in place for continuous improvement in accessibility features based on user experiences? 2. How adaptable is the building to emerging needs and technologies for enhancing accessibility?
		A.3	Reuse of stairs and elavators	How often do the elevators and stairs require maintenance, and what are the associated costs?	How do the stair and elevator designs impact the flow of people and congestion during peak hours?
		A.4	Location of of the vertical access	What is the average distance from key areas (like entrances, common areas, emergency exits) to the nearest vertical access point?	How do occupants and visitors perceive the convenience and accessibility of the current vertical access points?
	Insulation	B.1	Fire safety/ resistancy	1. What percentage of the building's total area is covered by the automatic fire sprinkler system? 2.What is the average time (in minutes) required for complete evacuation of the building during fire drills?	1. Are there any special considerations or safety features in place for individuals with mobility impairments during a fire emergency? 2. What fire-resistant materials and construction techniques were used in the design of this adaptable building? 3. Are there any environmentally friendly or sustainable fire-resistant materials or systems used in the building's construction?please explain about the strategies.
		B.2	Energy modeling	1. How closely do the actual energy usage metrics align with the energy modeling predictions? 2. What level of greenhouse gas emissions reduction is projected by the energy model, and how does this compare to actual reductions achieved?	1. How does the energy model accommodate the integration of renewable energy sources? 2. How does the energy model take into account climate variability and potential future climate change impacts?
		B.3	Moisture control	1. How does the building handle moisture control in areas that may experience high humidity, such as bathrooms or kitchens? 2. How has the building's design taken into account the potential for moisture infiltration or leakage during adaptation phases? 3. Can you describe the moisture-resistant materials and construction techniques used in the building's envelope, such as roofing and exterior walls?	1. What are the challenges in maintaining and operating the moisture control systems? 2. How does the building's moisture control strategy comply with health and safety standards and guidelines?
		B.3	Insulation material durability	1. What insulation materials have been used in the construction of the building, and how do they contribute to its energy efficiency and thermal performance? 2. What strategies are in place to ensure that insulation materials maintain their thermal resistance (R-value) over the building's lifespan? 3. Are there any insulation materials that are designed to be easily removed and replaced during adaptation phases to ensure ongoing performance?	1. How do the insulation materials affect the indoor environmental quality, including factors like air tightness, moisture control, and indoor air quality? 2. What is the environmental impact of the insulation materials, considering factors like production processes, embodied energy, and disposal?

Services	Light				
		E.1	Using natural ligh for interior spaces	1. What are the average illuminance levels (in lux) in key areas of the building due to natural light? 2. What is the ratio of glazing area to floor area, and how does it contribute to natural lighting? 3. What is the daylight autonomy (DA) metric for the building, indicating the percentage of annual work hours during which all or part of the building's interior achieves sufficient daylight levels?	1. Does your adaptable building prioritize the use of natural light in its design and layout? 2. Are large windows or skylights strategically placed to maximize daylight penetration into interior spaces? 3. Have you implemented light shelves or other architectural features to bounce daylight deeper into the building? 4. Is there an integrated system, such as automated blinds or shades, to control the amount of natural light based on time of day or occupancy? 5. Do you utilize daylight sensors to adjust artificial lighting levels in response to the available natural light?
		E.2	Optimize color use to light absorption/reflection	1. What is the percentage of incident light that is absorbed by the building's surfaces compared to that reflected? 2. How does the color optimization contribute to energy savings in terms of lighting and HVAC load reductions? 3. What is the luminous efficacy (amount of light output per unit of power input) of interior spaces after the implementation of optimized color use?	1. How does the color optimization influence the occupants' perception of space in terms of brightness and comfort? 2. Does the color scheme adapt to various functions of the building spaces and enhance the adaptability of the environment for different uses or user preferences?
		E.3	Location and size/shape of daylight facilities	1. How does the glazing area ratio (the ratio of window area to floor area) correlate with the thermal comfort and energy consumption for heating and cooling? (Energy modeling can be used to determine the optimal ratio for energy efficiency while ensuring adequate daylight.) 2. What is the contribution of natural daylight to the overall lighting energy savings? (Measurements of artificial light use with and without natural daylight can provide this information.)	1. What is the contribution of natural daylight to the overall lighting energy savings? 2. How do occupants perceive the quality of daylight in terms of visual comfort (e.g., brightness, glare, light distribution)?
		E.4	Lighting control	1. What is the overall reduction in energy consumption attributed to the lighting control system? 2. How frequently do users manually override the automatic lighting controls, and what are the reasons for these overrides? 3. How many hours per day/week are lights dimmed or turned off due to the presence of natural light or unoccupancy?	1. How do occupants perceive the effectiveness of the lighting control facilities in terms of comfort and convenience? (Surveys or interviews would gather subjective experiences regarding the use and satisfaction with the lighting controls.) 2. Do the lighting controls contribute to a sense of well-being and productivity among building users? (how well the system adapts to individual or group requirements.)
		E.5	Smart lightning system	1. What is the energy savings percentage attributed to the smart lighting system compared to a conventional lighting system? 2. How does the smart lighting system affect the building's peak load demand? 3. What is the frequency and duration of use for different lighting zones within the building? (Data analytics from the lighting system can track usage patterns.)	1. How do occupants describe their experience with the lighting quality provided by the smart system in terms of comfort and productivity? 2. Do users feel they have sufficient control over their lighting environment to meet their individual needs and preferences?
		E.6	Lightning zoning	1. How does lighting zoning contribute to the reduction of the building's overall carbon footprint? 2. What percentage of the building's floor area is covered by each lighting zone, and how does this correlate with occupancy and usage patterns?	1. How does lighting zoning impact the adaptability of spaces for different uses or events?
		E.7	Daylight harvesting	1. How do the occupants perceive the visual comfort provided by the daylight harvesting system (e.g., light levels, glare control)? 2. Do occupants feel that the daylight harvesting system contributes to their overall well-being and productivity?	1. What percentage of total lighting energy consumption is saved due to the daylight harvesting system? 2. What is the average illuminance level achieved in daylight-harvested areas during peak sunlight hours?
		E.8	Emergency Lightning	1. Is there feedback from emergency responders on the adequacy of the emergency lighting system in supporting their rescue operations?	1. What is the average response time of the emergency lighting system to power outages?

4.4. Études de cas

4.4.1. Habitations de Sainte Anne

Le projet de transformation de la maison mère des Sœurs de Sainte Anne est localisé à l'intersection de la rue Provost et de la rue Esther-Blondin dans l'arrondissement de Lachine, Montréal (*Figure 37*). Ce projet s'inscrit dans un plan d'ensemble visant la création d'une résidence pour personnes âgées autonomes, d'une résidence pour personnes âgées semi-autonomes, d'une résidence familiale et d'un parc municipal. À cela s'ajoute un volet de résidence privée de logements abordables.

Le projet en cours est celui de la résidence pour personnes âgées autonomes. Ce projet sera développé en mode design-construction à forfait (CCDC14) par le soumissionnaire retenu dans les ailes B, B+ et C (lot projeté 6 495 414) ainsi que dans l'aile A, soit la chapelle et ses espaces connexes (lot projeté # 6 495 415), la Maison du Chapelain (lot projeté # 6 519 836). Ci-après désigné comme étant les Bâtiments BB+C ou le « Projet ».

Les bâtiments A, B et C ont 5 étages, et l'agrandissement B+ aura 8 étages.

La rénovation majeure des bâtiments existants B et C ainsi que dans certaines portions de l'aile A existante qui est incluse dans le Projet pour une superficie totale d'approximativement 30 000 m².

L'aménagement existant (principalement des chambres et des locaux communs) ne convient pas au nouvel usage. Il est donc prévu de démolir l'ensemble des aires de plancher intérieures.

L'enveloppe sera conservée et bonifier pour couper les déplacements d'air. Les portes et fenêtres ayant atteint leur durée de vie utile, celles-ci seront remplacés. Des travaux de réfection d'enveloppe sont aussi inclus au projet, concernant principalement la pierre et la maçonnerie.

Nouvelle implantation proposée

Figure 37. Nouvelle implantation proposée

Un nouvel aménagement des aires de plancher sera fait pour intégrer 270 nouveaux logements allant de studios à des 2 chambres à coucher.

Des espaces communs seront également aménagés en conservant certains des emplacements originaux tel que pour la salle à manger et la cuisine. Les espaces au rez-de-jardins seront principalement réaménagés en salle de casiers, buanderie et salles mécanique.

4.4.2. Aéroport de Montréal – Parking 4

Le projet du stationnement P4 révolutionne la notion traditionnelle de stationnement en proposant une structure architecturale dynamique et fluide. Il met l'accent sur le mouvement, la lumière et l'observation des véhicules en mouvement au sein de cette construction.

Le nouveau bâtiment occupe une place centrale en accueillant divers modes de transport tels que les avions, voitures, bus, vélos et piétons, les intégrant tous dans une chorégraphie architecturale précise. Ce ballet de mouvements fait du projet un véritable portail entre la ville et le reste du monde.

La taille imposante du bâtiment est mise à profit pour offrir une expérience subtile et raffinée. Il est revêtu d'une enveloppe semi-transparente en aluminium qui réagit aux phares et à la circulation des véhicules, créant ainsi une immense toile de projection. Cette façade épique de 896 mètres de long et 18 mètres de haut, qui s'étend même vers l'autoroute adjacente au sud, se transforme en une surface lumineuse qui se fond dans son environnement.

Figure 38. Stationnement étagé de l'aéroport de Montréal . Source : (IAAQ, s.d)

Un talus végétalisé en face du bâtiment crée l'illusion d'une structure légère, tandis que des caractéristiques écologiques telles que la gestion des eaux de pluie et un toit vert contribuent à la durabilité du projet. Il s'efforce également de réduire l'effet d'îlot de chaleur et de favoriser la biodiversité.

En tant que projet ambitieux, le stationnement P4 intègre de nombreuses stratégies durables, notamment des panneaux solaires sur le toit, et vise la certification Envision Argent pour les infrastructures aéroportuaires canadiennes.

De plus, la conception du stationnement est adaptable pour répondre aux besoins futurs, notamment l'intégration de nouveaux modes de transport et d'accès. Il s'inscrit dans un plan directeur de 30 ans pour l'aéroport international Montréal-Trudeau, offrant la flexibilité nécessaire pour accueillir des développements futurs tels qu'un nouveau hall pour les passagers, une station du Réseau express métropolitain et un carrefour de transit. (IAAQ, s.d.)

4.5. Evaluation of the Bibliothèque – Gaston Miron

This heritage building housed the central library of Montreal. It was converted to house the Arts Council. Phase 2 of this conversion aims to restore the stone masonry envelope as well as the fenestration. The atrium ceiling is renovated, the ventilation system is modified to air-condition certain offices and the heating system is replaced. The work is carried out in the presence of asbestos and mold, in an occupied building.

The BMAA team carried out the curettages and precise surveys in order to detail all the hidden conditions. The various interventions required on the exterior envelope were organized by groups and numbered on the plans. A specialized quote was drawn up taking into account each element of this numbering. A detailed description of the interventions was developed. Photos of existing conditions have also been added to the quote to eliminate any ambiguity. This made it possible to represent particular conditions that had been identified during the surveys in the basket. Bidders thus informed were able to submit detailed and complete bids.

The restoration principles put forward in this project made it possible to restore this building to its original luster, while correcting certain degradation problems linked to the aging of the masonry.

A critical challenge in these studies was to retain the building's cultural significance and its public and community essence, factors that are crucial due to its historical importance.

The Gaston-Miron Building now features diverse cultural amenities that contribute to its dynamic atmosphere. It houses the Montreal Heritage Council in the basement, three rehearsal rooms and a spacious events hall on the main floor, and the Montreal Arts Council's offices on the upper level.


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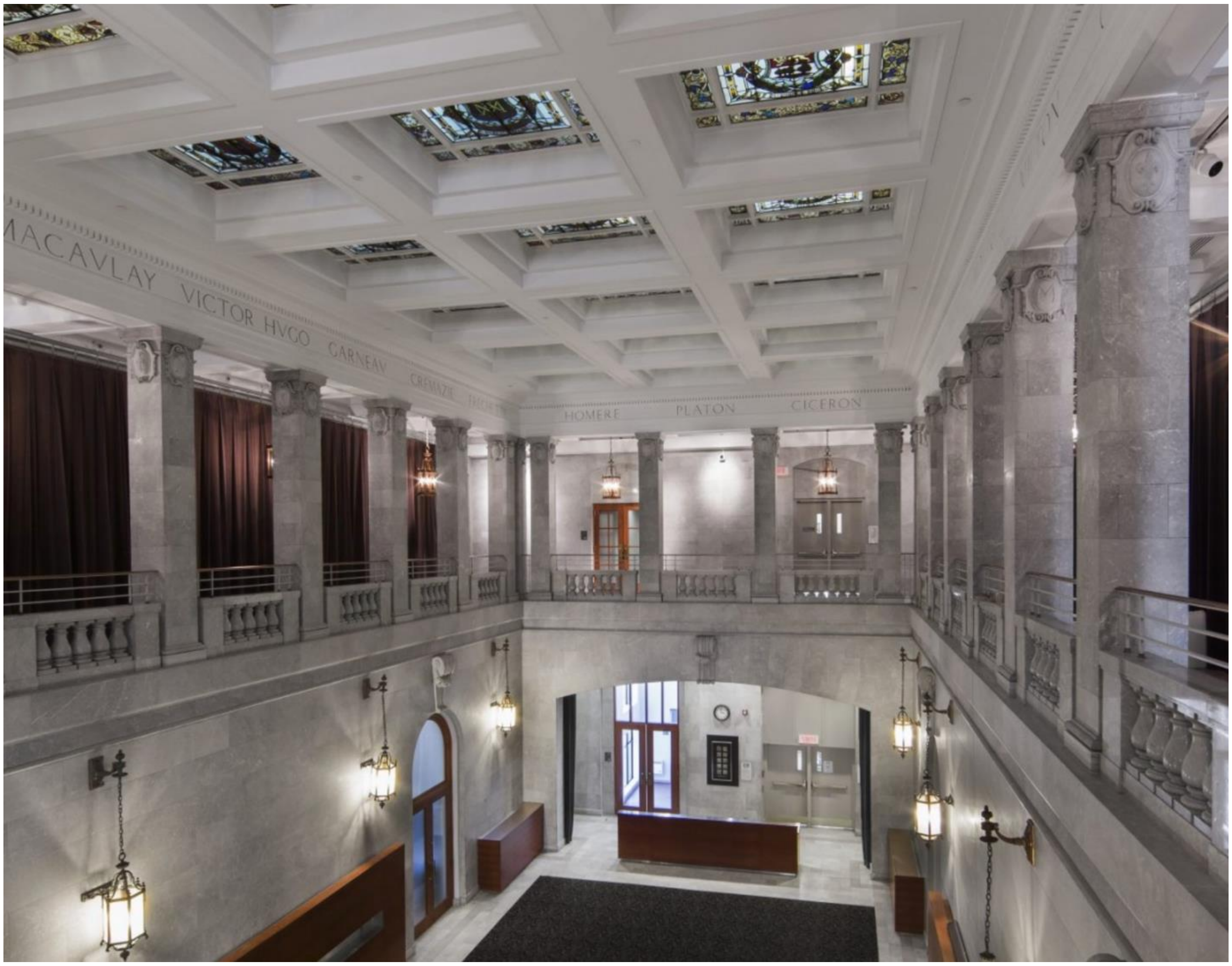
MACAVLAY
VICTOR HVGO
HOMERE
PLATON
CICERON

Bibliothèque – Gaston Miron

	Sub-criteria	Questions	Answers	Best condition	Worst condition	1	2	3	4	5
1	Diversity of the environment and site	How is the diversity of functions in the environments (e.g., commercial, residential, recreational) ?	It is located in city center and surrounded by residential, commercial and religious buildings.	The ideal stage of diversity in adaptable buildings is characterized by flexibility and inclusivity.	The least favorable stage in adaptable buildings is marked by isolating the building with limitted building with different funtionality					
2 3	Cultural and heritage preservation	.How does the adaptable building's design contribute to the preservation and integration of local cultural and heritage values? . What strategies are in place to ensure that any adaptive changes to the building remain sensitive to its cultural and historical context?	In the process of renovating a historic library, established in 1960 and situated centrally in the city, efforts were made to preserve its original function. This included the temporary relocation of all books to an alternate site during the renovation phase, with the intention of restoring them to their original location upon completion of the building work. Structural elements, particularly the walls featuring opals and glazing, were largely maintained, with modifications limited to certain sections for aesthetic or functional enhancements. All columns within the structure were retained, undergoing refurbishment to align with modern standards. The majority of the alterations were focused on updating the building's services and spatial layout to meet contemporary requirements, ensuring both the preservation of its historical integrity and the adaptation to current functional needs.	In the best scenario, building modifications respect and preserve the historical and cultural significance of the structure. This involves retaining key architectural features and historical elements that define the building's character. Renovations are carried out sensitively, blending modern functionality with historical aesthetics.	In the worst scenario, building modifications disregard the cultural and heritage value of the structure. Key historical features are often removed or altered beyond recognition to make way for modernization, leading to a loss of the building's original character and historical significance.					
4	Multifunctionality	Do you think this building has th potential to change the function over time? If yes,What design strategies are employed to ensure that the adaptable building can effectively serve multiple purposes over its lifecycle?	Currently, the building no longer serves as a library, with plans underway to repurpose its function. However, the extensive renovations and refurbishments carried out in 2011 and 2012 have enhanced its adaptability. Featuring an open space plan and a robust structural framework, the building is well-suited to accommodate a variety of other uses. This versatility stems from the strategic updates made in the past decade, which have not only preserved the building's integrity but also expanded its potential for diverse applications in the future.	An adaptable building features spaces that can easily transform to serve multiple purposes, catering to a wide range of activities and user needs. The design includes modular elements and smart systems that allow for quick and efficient reconfiguration. Such buildings effectively balance functionality, comfort, and aesthetics, making them highly efficient and user-friendly.	an adaptable building fails to offer genuine multifunctionality, with spaces being rigid, difficult to reconfigure, and limited in their use.					
5	Expandable site	How is the building's site designed to accommodate possible future expansion or downsizing?	The expansion of the building, either vertically or horizontally, is constrained due to several factors. Its status as an older structure poses limitations on vertical additions, ensuring the preservation of its original architectural integrity. Similarly, horizontal expansion is not feasible, given the surrounding urban landscape, which includes adjacent streets and buildings.	An adaptable building is designed with the potential for easy expansion, both vertically and horizontally, to accommodate future growth or changing requirements.	An adaptable building lacks any real potential for expansion, with a rigid structure that cannot be easily modified or extended.					
6	Building Codes and Regulations	What types of building codes and regulations are applicable to modifications in adaptable buildings?	some regulations in 2011 and 2012 were followed. (the detail were not reminded to interviewee	Adaptable buildings are designed and modified in strict adherence to current building codes and standards, ensuring safety, accessibility, and environmental sustainability.	Adaptable buildings fail to comply adequately with existing building codes and standards, compromising safety, accessibility, and environmental performance.					
7	Energy modeling	What energy modelling software or tools were used to design and analyze the building's energy efficiency?	For this building, no form of energy analysis was conducted.	Energy modeling is extensively utilized in adaptable buildings, guiding design and operational decisions to maximize energy efficiency and sustainability. This proactive approach involves simulating various scenarios to optimize building performance, leading to reduced energy consumption and lower environmental impact.	Energy modeling is either overlooked or inadequately used in the design and operation of adaptable buildings. This neglect results in inefficient energy use, higher operational costs, and a larger carbon footprint.					
8		How does the building's energy performance compare to industry standards or benchmarks for similar adaptable structures?								
9	Remote control and automation	1. Do you have a Building Management System (BMS) installed in your adaptable building? 2. Is your building's lighting system remotely controllable? 3. Does your adaptable building feature automated HVAC controls? 4.Is your building equipped with remote-controlled smart windows or shades?	The building lacks any remote control systems for its services or structural elements. All lighting systems are manually operated, and there are no remotely controlled shading devices. However, it is equipped with an HVAC system, which, to some extent, may have remote control capabilities, although this detail is not precisely recalled.	Adaptable buildings are equipped with advanced remote control systems that manage various building functions like lighting, temperature, and security efficiently.	Adaptable buildings lack effective remote control systems, leading to manual management of essential functions like lighting and HVAC, which is less efficient and more time-consuming					
10	Daylighting	How do the occupants perceive the visual comfort provided by the daylight harvesting system (e.g., light levels, glare control)?	The majority of the lighting fixtures and their placements have been retained from the building's previous incarnation as a library, where the lighting design was specifically tailored for that purpose. However, no formal analysis was conducted on the effectiveness of this lighting setup, and feedback regarding lighting satisfaction was not systematically gathered from the building's occupants.	Adaptable buildings are designed to maximize daylight harvesting, using strategically placed windows, reflective surfaces, and skylights.	An adaptable building fails to effectively utilize daylight, resulting in reliance on artificial lighting and increased energy consumption.					

11	Energy storage	Does your adaptable building incorporate an on-site energy storage system?	The building does not feature any energy storage solutions, nor is it outfitted with specific strategies for energy conservation.	Adaptable buildings are equipped with advanced energy storage systems, such as high-capacity batteries or thermal storage, allowing them to efficiently store and manage energy.	Adaptable buildings lack any form of energy storage, leading to a direct dependence on external energy sources and a missed opportunity to utilize renewable energy efficiently.					
12	Waste water treatment and local reuse	Have you integrated any graywater recycling systems within the building's infrastructure?	No	Adaptable buildings incorporate advanced wastewater treatment and local reuse systems, allowing them to recycle water efficiently for non-potable purposes like irrigation and flushing toilets.	Adaptable buildings lack any system for wastewater treatment and local reuse, resulting in the wasteful disposal of water and increased environmental strain.					
13	Smart water control	Does your adaptable building utilize smart water control systems to optimize water usage?	No	Adaptable buildings feature smart water control systems, utilizing sensors and automation to optimize water usage and reduce waste.	adaptable buildings lack smart water control systems, leading to inefficient water usage and potential wastage.					
14	Natural Ventilation	Could you describe any innovative strategies or technologies that have been incorporated to enhance natural ventilation?	The building equiped with mechanical ventilation but for natural ventilation just use windows.	Adaptable buildings are designed to maximize natural ventilation, using strategic placement of windows, vents, and atriums to facilitate air flow.	Aadaptable buildings fail to incorporate effective natural ventilation, resulting in stale, poorly circulated indoor air and an overreliance on energy-intensive mechanical systems.					
15	Façade windows to be opened	What is the projected lifespan of the window mechanisms, and what are the anticipated maintenance needs and costs?	Cost estimations were not specifically undertaken for these modifications, but it is noted that the building's façade was largely preserved in its original state, with renovations confined to select areas.	adaptable buildings feature façade windows that can be opened, allowing for natural ventilation and a connection to the outdoor environment.	adaptable buildings have façade windows that are fixed and cannot be opened, limiting natural ventilation and user control over the indoor					
16	Glazing (natural lights) and shading	However it is located in a very cold location, many glassess are used in façade. .Are there specific design principles that guide the selection of glazing and shading systems in the adaptable building?	The selection of glazing types did not involve energy simulations; instead, it adhered to the building standards prevalent in 2011 and 2012. Regarding thermal comfort, considerations were limited to ventilation, cooling, and heating systems, without conducting any detailed analysis.	The selection of glazing and shading systems in adaptable buildings is guided by specific design principles that prioritize energy efficiency, occupant comfort, and environmental responsiveness.	In the worst scenario, the selection of glazing and shading systems lacks clear design principles, leading to suboptimal choices that do not align with energy efficiency or occupant comfort.					
17	Moisture control	How has the building's design taken into account the potential for moisture infiltration or leakage during adaptation phases? Can you describe the moisture-resistant materials and construction techniques used in the building's envelope, such as roofing and exterior walls?	Certain specialized materials were employed to manage moisture levels, a crucial consideration given the building's original use as a library. However, specific details of these materials are not recalled. It is noteworthy that there were no instances of leakage reported.	Adaptable buildings are equipped with effective moisture control systems that maintain optimal indoor humidity levels, preventing mold growth and structural damage.	In the worst scenario, adaptable buildings lack adequate moisture control, leading to high indoor humidity levels, potential mold growth, and structural deterioration.					
18	Scalability of interior spaces	How is the scalability of the adaptable building defined in terms of its ability to accommodate growth or changes in space requirements? 2. Are there specific design principles or architectural features that enable the building's scalability?	The interior walls of the building offer flexibility, allowing for their removal or reconfiguration to enlarge or reduce spaces. This adaptability facilitates the accommodation of various functions within the structure.	In the best scenario, adaptable buildings are designed with scalability in mind, featuring flexible interior spaces that can be easily resized or reconfigured to meet changing needs	In the worst scenario, the interior spaces of adaptable buildings are rigid and inflexible, making it difficult to adjust or repurpose areas as needs evolve.					
19	joints	What innovative joining techniques are being employed in your design to allow for adaptability without compromising structural integrity?	Just used masonary and traditional joints and techniques.	In the best scenario, adaptable buildings utilize innovative joining techniques for structural and non-structural joints, enhancing flexibility and durability. These advanced techniques, such as modular connections and reversible fastenings, allow for easy assembly, disassembly, and reconfiguration of building components.	In the worst scenario, adaptable buildings rely on traditional, rigid joining techniques that limit the flexibility and adaptability of the structure. Fixed and permanent joints make it challenging to modify or repurpose building components, leading to a lack of versatility in the building's design.					
20	joints	In what way does the joint design support the building's capacity for future technological integrations?	Just used masonary and traditional joints and techniques.	In the best scenario, joint designs in adaptable buildings are meticulously planned to support future technological integrations, allowing for seamless incorporation of new systems and upgrades. These joints are designed to be flexible and modular, facilitating easy access for maintenance and the integration of advanced technologies like smart building systems. This foresight in design ensures that the building can evolve with technological	In the worst scenario, joint designs in adaptable buildings do not consider future technological integrations, resulting in a rigid structure that hinders the incorporation of new systems. These traditional joints complicate the process of updating or adding new technologies, often requiring extensive and costly modifications.					

5. Discussions

5.1. Sondage

Les résultats des entrevues ont été regroupés dans ce présent rapport et chaque question est commentée et analysée à part. Cependant, nous rappelons ici les objectifs prédéfinis au début de ce travail ainsi que le taux de leur atteinte.

- Collecte des facteurs de la conception adaptable
- Identification des types de bâtiments à adresser et les types de changement pour aller vers l'adaptabilité dans le contexte local : La majorité des projets identifiés dans le contexte local sont des bâtiments institutionnels. En deuxième lieu viennent les bâtiments résidentiels. Cependant, les changements fonctionnels sont les raisons les plus fréquentes pour l'adaptabilité. Ensuite, les raisons techniques et règlementaires suivent avec le même pourcentage en deuxième position. Tandis que les raisons politiques sont en dernier.
- Recadrement des critères d'évaluation identifiés dans la littérature
- Identification des stratégies de l'économie circulaire les plus efficaces pour l'adaptabilité : Selon les participants, la stratégie la plus efficace pour l'adaptabilité est la R4 – Réparer, qui consiste à réparer et maintenir les produits pour pouvoir les utiliser avec leur fonction originale. La remise à neuf des produits – R5 est la deuxième stratégie la plus efficace citée. Quant à la troisième stratégie, il s'agit de la réutilisation des produits qu'est la R3. En se basant sur ces résultats, ces trois stratégies sont les plus importantes.

5.2. Next steps

Numerous approaches and criteria have been developed in the framework to improve the adaptability of buildings, ranging from their design inception through to their maintenance, renovation, and eventual recycling phases. However, it's recognized that these criteria and sub criteria do not uniformly influence building adaptability. The subsequent phase of the project will entail arranging these criteria in alignment with the Canadian context, considering local climate conditions, material availability, and regulatory building codes. To effectively assess these criteria, it is imperative to establish a methodology that accounts for the specific circumstances of the building in question. The literature review sheds light on various evaluative methodologies pertaining to design for adaptability and the Circular Economy. At this juncture, the evaluation of the proposed framework necessitates soliciting both quantitative and qualitative feedback from stakeholders regarding pertinent benchmarks within the building context. Future stages of this research will involve crafting an evaluation tool that assigns ratings to this feedback, thereby assisting decision-makers in identifying the most efficacious strategies for building adaptability. Furthermore, the literature review will persist as an ongoing component of the research, with the anticipation of refining and augmenting the framework with additional specificity and detail in future iterations.

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