Adaptable Real Estate

The added value of adaptability in a long-term business case

Master Thesis | Bauke Brekelmans | June 2021

RE:BORN

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Abstract

Our cities have to expand either horizontally or vertically to accommodate the growing population and urbanization trends. Meanwhile, our needs, demands and desires evolve over time. This makes sustainable development and adaptability more relevant than ever. However, a main problem with adaptability is the additional investment costs against the lack of additional revenues. This lowers the financial return and disincentivizes to invest in adaptable developments. This claim is based on linear financial models that calculate on a rather short-term basis and only take the first function into account. The added value of the possibility to adapt to another function is not included in these financial models yet.

The aim of this thesis is to investigate different approaches towards adaptability and business cases that are needed among long-term owners specifically to incorporate the added value of adaptable features. A hybrid research consisting of literature research combined with a case study on adaptable tall buildings will be executed, to identify important adaptability features, and how to better incorporate them in a business case. Interviews have been held with both stakeholders of the selected cases, as well as with different professionals in the built environment concerning a long-term business case.

The results have shown that a building should not be regarded as one object, but merely as an ensemble of different building elements, each with a different lifespan. In addition, demountability has shown to be inherently connected to adaptability, and as means to achieve a more circular economy. By delivering a set of conditions on a technical, financial, organisational and a broader field, it is strived to contribute to increased implementation of adaptability in practice. By elaborating a roadmap for a more long-term business case, it is hoped to contribute to a smooth transition towards a more circular economy. In addition, this research aims to raise awareness, understanding and create incentives for adaptability possibilities.

Keywords: Adaptability, lifespan, tall buildings, financial model, circular economy, long-term.

"We should not try to forecast what will happen, but try to make provision for what cannot be foreseen."

- John Habraken (1961)

Preface

This graduation thesis represents the final product of a one year graduation research for the master "Management in the Built Environment" at the Faculty of Architecture and the Built Environment at the Delft University of Technology. The research started in September 2020 and is finished on the 30th of June 2021, the day that this research will be presented, and the memorable moment I will graduate from the University.

When starting with this thesis, my main aim was to find a topic and output in which I would be able to really contribute to current practice for a step towards a better real estate sector. During both my bachelor at Eindhoven University of Technology and my master in Delft, I was often confronted with the gap between scientific literature and how practice works. Now with the position of a researcher myself, I could do research on a topic that I have found very interesting all along; how to create a built environment that is less static and more able to change to desires and demands at that time. The topic of adaptability within tall buildings was created, with a personal interest in tall buildings as such dominant objects in our urban environments and modern society.

Doing a graduation research during the Covid-19 pandemic has been challenging. The working from home situation and not being able to meet fellow students physically to discuss small obstacles have definitely had their impact. It has been a fluctuating process where I learned many new things about the topic but also about myself, for which I am grateful. And of course I have had support and guidance from several people, for which I would like to take a moment to thank them.

First of all, I want to thank both of my mentors, Peter de Jong and Hilde Remøy, for their guidance and advise. Your criticism, knowledge and positivity have been very helpful. Thank you both for guiding me through the process and always being available for questions, and many thanks for the informal talks that were also very helpful in these abnormal times.

Another special thanks to Niel Slob, Lena van der Wal and Marcella Wong from RE:BORN as internship mentors for their enthusiasm and support, and for sharing their knowledge and feedback. Thanks to RE:BORN and all colleagues for the warm-hearted welcome to the organization and the efforts for involving me digitally.

Furthermore, I would like to thank the interviewees that took part in the research for their time and interest in this topic. I experienced the interviews as inspiring and compelling, and they motivated me in completing and delivering this research.

Finally I would like to thank my dear family and friends for their support throughout this process. I want to thank my mother, father, brother and boyfriend for their unconditional love and support, and for keeping up with me through the high and low periods that come with graduating. Most thanks to my mother and boyfriend who have always been there for me and helped me in their own ways, even though I was not the happiest all the time.

I have enjoyed the road, although it was a challenging road for me personally. In the end, it has brought me many insights and experiences that I am happy to carry with me in all future challenges that lie ahead of me. I am looking forward to the next chapter and in growing even more personally and professionally!

Enjoy reading!

Bauke Brekelmans
Delft, June 2021

Executive summary

Introduction
During the whole lifecycle of a building, change is unavoidable, both in needs and demands, as well as in social and economic context. Therefore, sustainable development and adaptability have become more relevant. According to Brundtland (1987) the definition of sustainable development is *"meeting the needs of the present without compromising the ability of future generations to meet their own needs"*. Adaptability can safeguard this, by allowing to easily alter the use of space, making it possible for occupants to use their floor areas more efficiently. This can lead to lower vacancy numbers. In addition, it allows buildings to stay occupied for a longer period by extending the functional lifespan. This also means that the imbedded materials are used for a longer period, or they are reused for a different function.

According to a report of Arup, BAM & CE100 (2018), the current financial models do not recognize value and risk in their most comprehensive forms, namely over the long run and taking the above-mentioned benefits of adaptability into account. For this reason, a shift from the current linear economy of 'take-make-dispose' to a more circular economy is needed in the built environment. The whole lifespan of assets needs to be considered, by also focusing on operational expenses (OpEx) instead of purely capital expenses (CapEx), to increase the asset's lifespan and usage.

Problem statement
The take-up of adaptability in new developments is not as high as is desirable from a social and environmental point of view. The main cause is that adaptability is thus far not motivating long-term owners and investors financially, while theory says that it certainly has financial benefits in the long run. Enhancing adaptability brings additional costs during the initial phase, but the additional value of it (by enhancing its adaptive capacity) remains unknown due to unknown changes in demands. In addition, the benefits lie with more stakeholders than the one that is paying for it, namely the owner. Most mentioned problems are related to the financial model that is currently used. Since this financial model is created in a linear economy, it has difficulties with the implementation of circular conditions such as adaptability. The value of adaptability is unseen and can therefore be regarded as lost value, since it is neither captured nor measured in the business case. It is believed that for a large step towards a more durable real estate stock, the business case and financial reasoning need adjustments.

Demarcation
Transformations happen in various sorts of buildings and functions. Yet the differences between different building typologies are too significant for transformations to consider them all together. This research focuses on tall buildings specifically, with the transformation possibilities to adapt from office to residential. There is no precise definition formulated for a tall building in the literature, yet this research takes the criterium of 70m.

Tall buildings are especially interesting in the field of adaptability, since everything related to tall buildings is expressed in extreme; the amount of materials, CO_2 emissions, the amount of stakeholders involved, development costs, and therefore also the additional investments for adaptability. It makes tall building development more difficult, yet more interesting to analyse. Another benefit with tall buildings lies in its replicability, with which you can make large impacts.

Research questions
To address the problems concerning adaptability and it's long-term benefits, the following main research question has been answered:

"What business model and financial model are most appropriate for real estate organizations to achieve increased adaptability in tall buildings?"

The following sub-questions have helped to steer the research and to find the answer to the main question:
- What features have to be incorporated in order for a tall building to be adaptable?
- Which approach for a long term lifespan (for an adaptable building) can be best used?
- To what extent is adaptability taken into account in the current financial model?
- How can the financial model be changed so that adaptability benefits and costs are taken better into consideration?

Research method, goal and output
The research questions are answered by a thorough literature research and case study research. A literature research has been conducted to explore different terminologies, theories and definitions of adaptability, lifespan and circularity, and to identify key variables for adaptability. In the case study research, the features identified in the literature research have been tested and compared. Four cases have been selected for the case study over different phases concerning transformation. The case study is complemented by interviews with stakeholders. In addition, interviews with professionals concerning the long-term business case have been held.

The goal of this research is to make the financial benefits of adaptability visible and workable. In the end, the larger goal is to maximize the value of resources that are already invested in the current stock, and to decrease the usage of resources and the emission of CO_2 for the future developments. This will also contribute in the decrease of vacancy of tall office buildings.

The research strives to gain insights and deliver conditions under which it is possible to improve a business case in a more circular manner. These conditions that are based on scientific research can then be applied in practice by initiators of a development in reconstructing their own financial models.

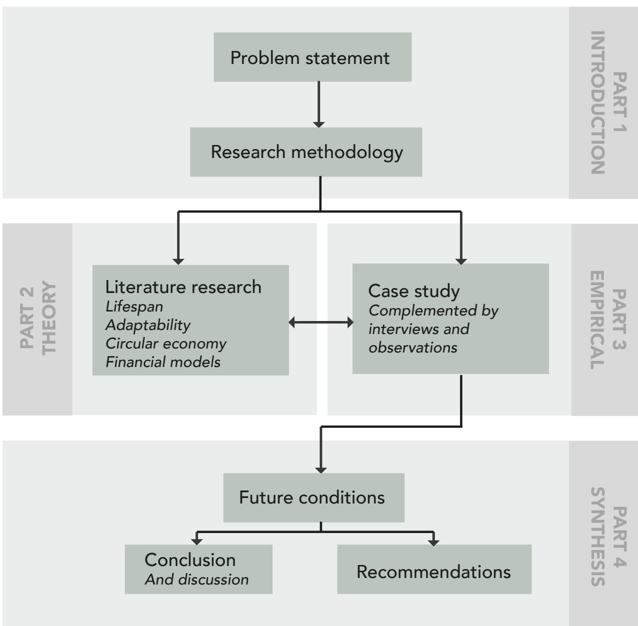


Figure A. Research framework (own illustration).

Results from literature research

Lifespan

The lifespan of a building is an estimation of time. The estimations vary across countries and depend on functional requirements, materials, geographic and climate conditions (De Jong & Wamelink, n.d.). Most of the time a lifespan of 50 years is used, but this can be higher for dwellings and lower for offices. De Jong & Wamelink (n.d.) appeal for the use of 200 years as lifespan, because 50 years is simply too short for a durable building that allows multiple uses in a lifespan.

The lifespan of a building often differs from the lifespan of the separate elements. The literature describes different approaches towards the layering of a building.

- Frank Duffy (1990) defined three distinctive building layers in office buildings, which are the shell (50 years), services (15 years) and scenery (5 years).
- Stewart Brand (1994) later adapted Duffy's approach, which he called the shearing layers of a building (figure B). It demonstrates a building in the 6 layers of Site, Structure, Skin, Services, Space plan and Stuff, wherein all layers are adjustable and demountable in their own and in relation to each other.
- De Jonge (2000) takes another approach on the lifespan of buildings by making a distinction between the technical, functional and economic lifespan respectively.

The layers of Brand (1994) forms the most comprehensive approach and is taken into consideration in the empirical part.

Adaptability

Various definitions are used in the literature for adaptability. This thesis adopts the definition of Schmidt et al. (2014), which is *"the capacity of a building to accommodate effectively the evolving demands of its context, thus maximising its value through life"*

Adaptability is not a goal, but rather the means to an end, in this case sustainable development and a more circular economy.

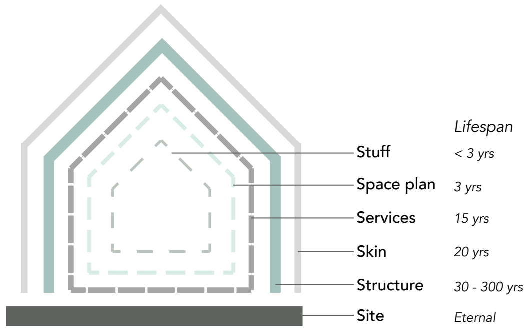


Figure B. The six layers of a building according to Stewart Brand (1994).

Flexibility is often used interchangeably with adaptability, but literature mentions some differences. It can be said that flexibility can be interpreted as allowing changes within a building, and adaptability goes one step further in allowing changes by adapting the building.

The features identified for increased adaptability are divided into legal and technical aspects, and are summarized in table C.

Table C. Overview of features to increase adaptability

Legal	
	Land-use plan flexibility.
	Building Decree compliance.
Technical	
Structure	Generic and flexible layout: a central core or horizontal corridor.
	Free floors; Wide floor slabs loadbearing in two directions.
	Grid measurement of 1,8 m preferred.
	Small span core to facade; 5,4 m - 7,2 m - 9,0 m.
	Floor-to-floor height 3,6 m.
	Possible for horizontal floor extensions.
Skin	Design the facade as demountable and adaptable.
	Keep distinction between long-cyclical and short-cyclical facade.
Services	Locate services around or in the core.
	Never integrate services with structure.

Circular economy
The circular economy is designed with the aim to extend the life of products as long as possible, with having the highest value possible (Circle Economy, 2019). It differs from the linear economy in setting two additional value creators besides economic value, namely environmental and social value.

Demountability is at the heart of enabling a circular economy. To allow buildings to be adaptable, disassembly of products is needed. Disassembly also allows for harvesting products, elements or materials which can be reused elsewhere.

Within a circular economy, Total Cost of Ownership (TCO) answers to the need for a cost approach to learn the total costs and benefits of real estate objects throughout the whole lifecycle. A benefit of TCO is that the final decision represents the total cost commitment of a facility, risk and performance, rather than the initial costs only (Manewa, 2012). Besides, it provides a framework which allows to compare options at all stages of the development. In comparison to traditional valuation methods, TCO often leads to more detailed results.

Yet the circular economy can go one step further by also including energy costs, facility costs, and the residual value (on building level or component level). The empirical part therefore opts for a circular economy approach as most comprehensive and integral approach.

In the linear economy products and buildings have a negligible value at the end of their economic lives, and are therefore depreciated to € 0. In a circular economy, where products and materials are continuously retracted and reused, there is always a residual value. However, literature mentions the lack of information for estimating the residual value of elements, but steps are taken in developing instruments and measurement tools.

Financial models
In the current linear economy, the most frequently used methods are the static methods of the Gross Initial Yield (GIY) and Net Initial Yield (NIY), and the dynamic methods Net Present Value (NPV) and the Internal Rate of Return (IRR). The Net Present Value method is the preferred method for the long-term business case, since it includes all cash flows, meaning both operating and capital expenses. This means the benefits of adaptability should be somewhere visible in this method.

Results from case study research
Four cases have been chosen for this study: Park Hoog Oostduin and The Lee Towers are two cases that have already been adapted to residential, De Nederlandsche Bank is currently being adapted, and the Faculty of Aerospace Engineering at TU Delft is explored to be adapted in the future.

Park Hoog Oostduin and The Lee Towers
Main lessons learnt:
- Design the structure as flexible, while all other layers need to be adaptable by being demountable.
- Keep the core flexible and generic, by including only the essentials and excluding function-specific facilities from the core.
- Make a distinction between parts that are most subjectable to change and design it with as little resources as possible, and parts that are least subjectable to change to be demountable to take to other locations.

De Nederlandsche Bank
Main lessons learnt:
- There is also a difference in lifespan due to its function and the degree of usage. The differences among functions are larger in the short-cyclical layers, while the differences are smaller in the long-cyclical layers.
- Early involvement of different expertises is very important, leading to substantial research and analysis of the building upfront.
- Incorporate several checks and balances along the process by establishing Service Level Agreements with other parties.

The financial exploration has shown that with the circular way of harvesting and reusing elements, a saving of € 330 K is realized after reconstruction. In addition, by incorporating a residual value and environmental costs, a saving of € 7.3 million has been realized on the two layers of structure and skin, compared to the traditional way. The exploration also demonstrated that the value on material level is almost negligible on high development costs. So residual value must be safeguarded on element level to really add value in the long-term.

Faculty of Aerospace Engineering
The financial exploration of the Faculty of Aerospace Engineering has been evaluated as not reliable enough, and therefore not valuable, due to the high amount of assumptions that had to be made because of a lack of data and information. It is for these reasons that the researcher has decided to not continue with this exploration.

Explorative cross-case comparison
A cross-case comparison has been made to expose the underlying differences and to validate the findings of the literature concerning the technical adaptability features. The main differences were found in the ownership situations, and in several technical design choices concerning the structure and skin. A quantitative comparison showed that based on the technical features found in the literature, the Lee Towers showed the highest adaptive capacity, followed by De Nederlandsche Bank.

Results from interviews long-term business case
The main lessons learnt concerning a long-term business case that have been derived from interviews with professionals in the built environment are:
- Lifespan of 30 years is currently mainly used.
- Three areas to take into consideration with an intervention: Technical lifespan, Internal ambitions and External regulations (figure D).
- There must be steered on demountability to achieve increased adaptability. Adaptability is then needed for achieving a circular economy (figure E).
- Demountability depends on four factors:
    - Type of connection
    - Accessibility to the connection
    - Whether it has been crossed
    - Form embracement

  It is important to steer on those four aspects in the design phase on choices to be made.

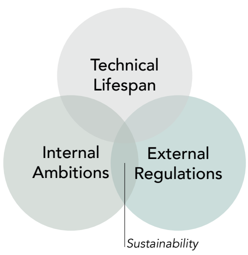


Figure D. Different factors that influence interventions (own illustration).

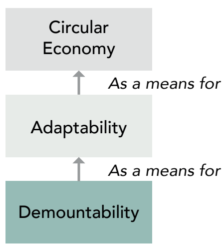


Figure E. Different means to achieve a circular econoxmy (own illustration).

- Residual value can have 3 different levels:
    - Reuse value 1-on-1
    - Reuse value, but refurbishment is needed
    - Recycle value on material level
- Early involvement of an investor can help in stimulating sustainable (financial) choices.
- Other strategies for adaptability are over-dimensioning, and requestioning the actual need for space.
- Adaptability can only be increased by both stimulating the demand side, and by redesign from the supply side. An important condition is for suppliers to improve their product designs and how demountability is assured.
- There is a need for a database, market place or platform to exchange harvested materials. This database should also be provided with more and reliable information from the suppliers about its value.
- Material passports need to be implemented to a larger extent, for recording the value of materials over time, how it is constructed and where it originates.

Conclusion
The following answers have been given on the sub-questions, leading to an answer for the main research question.

Sub-question 1: What features have to be incorporated in order for a tall building to be adaptable?
To be adaptable means a building can adapt at the end of its functional lifespan to another function, where a new functional lifespan can start off. Therefore, a building needs to be seen in different layers that are independent from each other, meaning each element and layer is adjustable or replaceable without affecting the other layers. This needs to be taken into account in the design phase already. Secondly, demountability is a fundamental feature and a means for achieving adaptability. The more a building is composed out of demountable elements, the easier it is disassembled and the more common adaptable building practices and reuse of elements can become.

An overview of the most important features retrieved from the literature research and the interviews has been provided in chapter 6 Synthesis.

Sub-question 2: Which approach for a long term lifespan (for an adaptable building) can be best used?
Buildings should not be considered as being one object, but as the sum of different objects. For this, the layers of Brand (1994) are the most comprehensive and close to practice to implement. Ranges are used since lifespans depend on the materials used, as well as the level of maintenance executed over its life. There is no single approach for estimating the lifespan of an adaptable building, but an answer can partly be given by providing a comprehensive overview of the influencing factors. In this way, the absence of a comprehensive approach is thus an answer to the sub-question.
- The longer the lifespan, the more the focus lies on flexibility instead of adaptability or demountability.
- The longer the lifespan, the more fixed the elements and connections often are.
- The longer the lifespan, the lower its residual value on element level will be (but the residual value lies more on the whole ensemble).
- The longer the lifespan, the smaller the differences between lifespans among different functions are.

Sub-question 3: To what extent is adaptability taken into account in the current financial model?
For this question, the interviews have been used to gather insights about the current situation regarding adaptability and the financial models.

In a traditional financial model, only the additional investment costs for adaptability are taken into account in the construction costs, without considering the financial benefits. Approaches such as Total Cost of Ownership and Life Cycle Costing are still not widely adopted in the built environment, because of a lack of fiscal measures and lack of reliable and relevant information and data. Also, demountability has gained no real recognition yet in new developments, as these ideas on demountability as part of adaptability and durability are brought up more by architects as design principle than by clients as requirement. The cases of this graduation research have also demonstrated this low adoption of adaptable approaches in the financial model.

A building is traditionally developed for one lifespan and one function, which makes adaptability and demountability irrelevant topics for only one function. Literature mentioned that traditionally a lifespan of 50 years has been taken, while the interviewees mentioned a lifespan of 30 years has been taken in current financial models. Still, the long-term perspective beyond 50 years is not taken into account.

Sub-question 4: How can the financial model be changed so that adaptability benefits and costs are taken better into consideration?
The answer has been elaborated in chapter 6 Synthesis, as it elaborated a roadmap proposal for an improved long-term business case in which the value of adaptability can be better included. As a recapitulation, the eight steps of this roadmap are:
1. Extend the investment period.
2. Separate the investment over building layers.
3. Include residual values.
4. Adjust the depreciation method.
5. Include environmental costs.
6. Include social and ecological value
7. Include transformation costs.
8. Adjust the way of financing.

Main question: "What business model and financial model are most appropriate for real estate organizations to achieve increased adaptability in tall buildings?"
There are different traditional and more circular business models currently used in real estate development. In general, a shift from ownership to services is recognized among the more circular variants. Here again, the relevance of ownership emerges. Still both literature and empirical findings underpin the lack of knowledge on development of value over time with leasing business models and other more circular business models.

It can be said that for each layer, a different business model could be applicable, based on the costs and benefits and processes needed. It is project-specific to determine what business model is most reasonable to use per building layer. There are two business models, Resource Recovery and Product Life Extension, that can be focused on during a project by developing a strategy for it. In this way, adaptability is ensured in the development which could lead to financial incentivization as well.

As for the business case, this research has demonstrated that the traditional business case is able to extend and evolve towards a more circular and long-term business case. To the question what financial model is most appropriate, it can be answered that the traditional model is still the most appropriate basis, but is in desperate need of alterations. The alterations have been mentioned with sub-question 4.

Discussion

Obviously, there are some critical notes to be taken on the retrieved information and results. First of all, the chosen research has been qualitative and explorative in its origin. In some parts, there was often more information retrievable on soft values rather than hard and financial values. This has led to different levels of quality per case. Also, different professions have been interviewed, leading to different perspectives on topics that should be noted carefully. Because of the different levels of depth and quality in the case study and interviews, the results also vary.

Secondly, the case selection has been determining for the research process and results. During the empirical research, demountability became more relevant for adaptability, but only one case was actually demountable. Looking back it is believed that a case study with demountable cases could perhaps have contributed more towards the posed problem.

Also, most office transformations have been executed with smaller office buildings. Here, many potentially useful cases could have been missed by focusing on buildings higher than 70 m.

During the interviews it became clear that with three cases there was not steered on adaptability, which made part of the interview less useful since depth could not be reached on this topic. It was assumed that adaptability was a main focus that has been steered on, and that was taken into account for the future as well, but this should have been analysed more thoroughly.

Adaptability cannot be taken into account to the same extent with transformations as for new developments; there lies an important difference, since the design phase has already passed. This thesis has focused on transformations in which there has been looked at various adaptable building characteristics, but still their adaptive capacity can be lower than for new developments. It can be questioned if the design phase would have been more interesting to research than the transformation phase.

The different phases have perhaps been too broad to all take into account for a graduation research, within the restricted time planning. For a next time, the same phase would have been taken for a case study.

Limitations

The first limitation of this graduation thesis is the lack of data on certain cases that could not have been anticipated. Even though all interviewees had agreed on doing the interview, not all interviews have been executed due to ignorance from the interviewee. This has resulted in less input and data, which makes the results less reliable.

The interviewees of chapter 4 have been selected based on their alleged expertise on real estate and financial models. No rigorous criteria have been used, which has resulted in different backgrounds and perspectives towards the built environment. This can lead to certain biases from the interviewees in the answers provided. In addition, the results cannot be related to a single professional perspective.

Lastly, the limitation of Covid-19 had influence on the process and the final results. Because different forms of lockdowns had been called out over the year, this thesis has been written mainly from home. It could be a realistic assumption that during the process, the amount of feedback moments and sparring moments have been less than regular.

Reliability and usability
The reliability of this thesis has been guaranteed during the case selection. The chosen cases have similar characteristics and typologies, which increased the reliability of findings for tall buildings and these tall building typologies specifically. However, the results are based on the four cases only, meaning that the findings need to be validated for other typologies as well to increase the applicability.

The interviews and results of professionals concerning the long-term business case are based on personal views of experts. If this research would have been conducted again in a similar way, yet with other interviewees, the results of this research could have been different, which decreases the validity of this research.

In addition, the interviews have been prepared by different interview protocols because of the interviewee's different backgrounds. This means not all interviews could be easily compared to each other; only on some topics there was overlap.

All in all, the validity of this researched has been maximized by the use of triangulation of data (Bryman, 2012). This means the usage of multiple data sources for case and cross-case analysis, such as documentation, internet sources, observations and interviews with both stakeholders and professionals. In this way, the qualitative nature of the research has been substantiated by as much different types of sources, for decreasing the dependency on context-specific aspects.

Recommendations

Scientific recommendations
- Increase scientific evidence on lifespan estimation.
- Increase research on the perspective of user concerning adaptability and its benefits.
- Increase knowledge on the value of demountability and the interrelations of demountability and adaptability.
- Conduct quantitative research on the (long-term) business case in retrospect.
- Conduct similar studies with other typologies and functions.

Practical recommendations
- Do not wait for others, but explore yourself.
- Join forces cross-disciplinary.
- Invest in data gathering and processing.
- Consider the vital role of clients.
- Consider the accelerating role of the government
- Steer upfront instead of measure afterwards.

Table of content

I.
Introduction

I. Introduction

The introduction starts with a description of the problems that have become the main motives for this research. This leads to the posed problem statement, followed by research questions and an elaboration of the methodology that are used to execute the research and create new insights.

1.1 Problem description and research background

It is known that the majority of the people are living in urban environments, and this number is still growing. By 2050, 66% of the world population is expected to live in urban environments, while this was 54% in 2014 (United Nations, 2014). To accommodate the growing population, cities either have to expand horizontally or vertically, or vacant buildings will be transformed to another function. Normally buildings are developed for a specific function, and once developed it remains difficult to transform the building into another function due to technical, legal, functional or financial constraints (Schenk, 2009). As a result, more buildings become obsolete and vacancy numbers increase. In the Netherlands, the total vacancy rate in real estate amounted to almost 30 million m² in 2020 (Landelijke Monitor Leegstand, 2020).

During the whole lifecycle of a building, change is unavoidable, both in needs and expectations of users, as well as in social and economic context. Our needs, demands and desires evolve over time, and so should the things around us. Yet our buildings are designed with a static nature which obstructs it from accommodating these changes. Therefore, sustainable development and adaptability of buildings have become more relevant. According to Brundtland (1987) the definition of sustainable development is *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."* One prerequisite for creating sustainable buildings is to consider the whole lifecycle of a building from the initiative phase already. This means the tools and methods used in the current industry will need a lifecycle focus as well.

By looking at transformations, the main benefit of adaptable buildings is that the use of space can be altered quite easily, making it possible for occupants to use their floor areas more efficiently when facing changing needs. Especially with new office concepts and flexible working spaces, a more efficient use of office space can be created. This leads to a decrease in the amount of m² used per employee, which results in an increase in redundant space within an occupied office building, also called the unregistered or hidden vacancy (Remøy et. al, 2013). By increasing the capacity to adapt, the hidden vacancy will be lowered. But there are more benefits with adaptable buildings. First it allows buildings to stay occupied for a longer period (Russell & Moffatt, 2001). The functional lifespan of a building is extended, which leads to a delay in repurposing or demolishing the building. In addition, future technological innovations could be implemented more easily and at lower costs with an adaptable building. Thirdly, by increasing the lifespan the materials are used for a longer period. Instead of being demolished and disposed, the materials are re-used.

From an environmental point of view, it is important that the demand for energy, land and materials needed for new construction needs to be mitigated (Conejos & Smith, 2013). This can be done by taking better care of the existing building stock. Either by transforming them if they have already been developed, or by investing in solutions for increased adaptability in future developments.

Yet, the main problem is that enhancing adaptability brings additional costs during the initial phase. Of course these costs give a certain additional value to the building since it enhances the flexibility, yet the additional investment can be difficult to justify given the high degree of uncertainty for future demands (Russell & Moffatt, 2001). Therefore it remains an investment made voluntarily for improved performance of a building. Furthermore the benefits lie with more stakeholders than only the developer who is paying for it. Yet the developer is the one that is particularly important in this shift towards adaptability, since they are involved throughout the whole development process. In addition, their impact is the largest in setting the direction of the development strategy and ownership structures. But they are also the ones estimating the risks of certain decisions, which makes their risk appetite and perception two important characteristics.

According to a report of Arup, BAM & CE100 (2018), the current financial models use past performance to calculate future results, and they rely on a system that is fit for purpose. These systems do not recognize value and risk in their most comprehensive forms, namely over the long run and taking the benefits of adaptability into account. In addition, it is necessary that assets are viewed with the focus on operational expenses (OpEx) instead of capital expenses (CapEx) to increase the asset's lifespan and usage. By additional investments in the initial phase it is believed that the operational expenditures can be lowered. This means that a shift from short-term to long-term profits is necessary. It is mentioned in the literature as a shift from the current linear economy of 'take- make-dispose', to a future circular economy. This shift is very relevant since a lot of embodied energy (energy and resources that have been 'locked' in developed buildings) will be lost with the demolishment of buildings while they often have not yet reached the end of their service life (Conejos & Smith, 2013). We cannot continue on the same foot because the limited resources that are available today cannot sustain this pattern. Therefore other approaches and business models are needed among real estate developers and investors.

Thinking in a circular way can allow for better models that can measure and quantify social and environmental impact, and deliver a stable economic performance simultaneously. And obviously, an adaptable building positioned on a location with mixed functions can be even more interesting for investors, because of its potentials, lower risks and a higher taxation of the asset. Yet there is a large challenge ahead of us to motivate long-term owners of such benefits, or to create incentives.

1.2 Problem statement

The take-up of adaptability in new developments is not as high as is desirable from a social and environmental point of view. The main cause is that adaptability is thus far not motivating long-term owners and investors financially, while theory says that it certainly has financial benefits in the long run. Enhancing adaptability brings additional costs during the initial phase, but the additional value of it (by enhancing its adaptive capacity) remains unknown due to unknown changes in demands. In addition, the benefits lie with more stakeholders than the one that is paying for it, namely the owner. Most mentioned problems are related to the financial model that is currently used. Since this financial model is created in a linear economy, it has difficulties with the implementation of circular conditions such as adaptability. The value of adaptability is unseen and can therefore be regarded as lost value, since it is neither captured nor measured in the business case. It is believed that for a large step towards a more durable real estate stock, the business case and financial reasoning need adjustments.

1.2.1 Demarcation of research

Transformations happen in various sorts of buildings and functions. Yet the differences between different building typologies are too significant for transformations to consider them all together. This research will therefore focus on tall buildings specifically, with the transformation possibilities to adapt from office to residential. This selection can be justified by the fact that vacancy is still rather large among offices. In the third quarter of 2020, office vacancy accounts for 8,2% of the total office stock in the Netherlands (Cushman & Wakefield, 2020). Besides, tall buildings are often office, residential or multifunctional (Council on Tall Buildings and Urban Habitat, 2020a). In addition, there is still a mismatch in demand and supply of dwellings in the Netherlands. Lastly, previous transformations have mostly been applied to offices that are adapted to dwellings (van der Voordt et al., 2007).

1.2.2 Definition of tall buildings

There is no precise definition formulated for a tall building in the literature. There are different sources with varying definitions and arguments. The Council on Tall Buildings and Urban Habitat (CTBUH, n.d.) explains that it depends on the height and the context in which the building is located. Therefore what tall means remains relative, and this goes for the proportions as well (whether or not it appears to be slender or have a high footprint). The Dutch Building Decree names it a tall building if there is an elevator in the building, and this is required for buildings of 5 floors or higher. The three municipalities that have established their own municipal visions for tall buildings differ in their definitions as well (table 1).

Table 1. Definition of tall building per municipality (Retrieved by 3 municipal visions for tall buildings).

Municipality of Rotterdam	Buildings with a minimum height of 70 meter.
Municipality of Amsterdam	Buildings with a minimum height of 30 meter or twice the height of buildings in the vicinity.
Municipality of The Hague	Buildings with a minimum height of 50 meter.

Since this thesis will most likely focus on the Dutch building stock, the highest criterium of 70 meter will be used to define a tall building. With this definition, there are currently 225 tall buildings in the Netherlands (completed or under construction) (Council on Tall Buildings and Urban Habitat, 2020b). The majority is located in Rotterdam, with Amsterdam coming second.

Tall buildings are especially interesting in the field of adaptability for several reasons. First of all, everything that has to do with tall buildings is expressed in extreme. Tall buildings in particular consist of a vast amount of materials and emitted a large amount of CO_2. As a result, the costs of developing a tall building are also extremely high. This makes the justification of additional investment costs for adaptable features even harder, since it puts more pressure on the business case. And thirdly, tall buildings are often multifunctional, which leads to more stakeholders being involved, as well as larger design and construction teams. All above mentioned aspects make tall building developments more difficult, yet more interesting to analyse since its impact will be substantially larger.

Another general benefit with the transformation of a tall building lies in its replicability; By transforming a tall building you can make a large difference by significantly reducing the amount of vacant m^2 and adding a substantial amount of dwellings. These scale benefits emphasize the relevance of tall building transformations even more.

1.3 Relevance

The relevance is the foundation for conducting a specific research; if there is no relevance towards society, science or the world, there is no need to continue. This section elaborates on the societal and scientific relevance, as well as the personal motivation behind this research.

1.3.1 Societal relevance

With the current Covid-19 pandemic, our patterns of work have changed abruptly. People in different sectors are forced to work from home, and corporations have seen the benefits and drawbacks of flexible working. However, the transition from working in offices to working (partly) from home went gradually for the past 20 years, yet has now accelerated because of the pandemic. This leaves many organizations with the question what to do with their office spaces. This is one example that shows that real estate should be adaptive to prevent buildings from being vacant, and to utilize the space in the cities in the optimal way, whatever the circumstances and demands are at that moment.

By the growing cities and the need for space on the one hand, and the constantly changing society and related real estate demands on the other hand, it is important to increase the amount of adaptive tall buildings in the future. But the relevance of adaptive tall buildings is manifold. From the perspective of resources, it is important that the vast amount of materials being invested in our built environment can be re-used where possible. The building and construction industry together account for 39% of global CO_2 emissions, which includes the manufacturing of materials and products (UN Environment and International Energy Agency, 2017). In addition, 25% to 30% of all European waste can be accounted to construction and demolition waste (European Commission, 2016). By transforming buildings instead of demolish and construct again, this number can be cut down. The natural resources, CO_2 emissions and energy that were embodied during construction will serve for another function and will not be disposed yet. Moreover, when tall buildings are taken together, they form a skyline that is often a distinctive feature for a city. This dates back to the first high-rise buildings in New York and Chicago whose most important function was to impress and to be dominant in the city's image (Meyer & Zandbelt, 2012). Municipalities and inhabitants have a desire in maintaining that skyline and allocating possible other functions in the tall buildings to keep them occupied.

1.3.2 Scientific relevance

There is a vast amount of literature that have researched the benefits of adaptability in the long run and theoretical implementation of adaptability (Remøy, 2010; Russell & Moffatt, 2001; Slaughter, 2010; Sadafi, 2014; Schmidt et al., 2010). Yet the translation of adaptability to practice needs extra attention, which is what this thesis aims to cover. Literature suggests that the benefits of additional investments in adaptability will be paid back in the form of lower adaptation costs in the future (Pinder et al., 2011), yet this has not been supplemented by actual evidence. Lastly, this thesis addresses a subject that is relevant both from the perspective of the technical studies within the built environment, as well as the field of economics and finance. By involving these two disciplines, it is believed that new insights can be obtained.

1.3.3. Personal motivation

My personal motivation for this research is to make significant steps in adaptability, so that we make better use of the real estate that is already there and the residual life embedded in them. I have always had a fascination for monumental buildings and the way they were constructed with such little industrial and technological tools. What I find even more interesting since my studies is how those buildings have lasted until now, and what function they fulfil within our societies. I find it very important that we learn to make lasting buildings again, and here I believe adaptability is a key principle in our fast-changing society. The choice for tall buildings can be justified by the fascination for modern society, which is in contrast with the monumental buildings mentioned before. The tall buildings developed by our generation will hopefully be our legacy, and therefore we should rethink our way of designing them.

1.4 Research questions

The fields of adaptability and tall buildings have many topics where further research is still needed for a better implementation in practice. This research aims to answer the following research question:

> *"What business model and financial model are most appropriate for real estate organizations to achieve increased adaptability in tall buildings?"*

Sub-questions (figure 1):

- *What features have to be incorporated in order for a tall building to be adaptable?*
- *Which approach for a long term lifespan (for an adaptable building) can be best used?*
- *To what extent is adaptability taken into account in the current financial model?*
- *How can the financial model be changed so that adaptability benefits and costs are taken better into consideration?*

Sub-question 1
What features have to be incorporated in order for a tall building to be adaptable?

Sub-question 2
Which approach for a long term lifespan (for an adaptable building) can be best used?

LITERATURE STUDY

Sub-question 3
To what extent is adaptability taken into account in the current financial model?

Sub-question 4
How can the financial model be changed so that adaptability benefits and costs are taken better into consideration?

CASE STUDY

Figure 1. Relations among sub-questions (own illustration).

1.5 Research output
The main goal of the research is formulated in this section. In order to reach the goal, the objectives have been translated into a research plan.

1.5.1 Research goal
The aim of this research is to gain insights about an important link between adaptability and the real estate development process of tall buildings. Here the perspective has been taken from the stakeholders that are involved throughout the whole process and can therefore contribute significantly, namely the long term owners. They are the ones that will experience the benefit of adaptability in the long term, which makes an improved investment case fundamental for them. But the importance is felt by the whole industry to adopt more circular economy principles and to decrease the environmental footprint of the industry as a whole. Because what we see as morally right and desirable, should also be financially profitable.

Adaptability should be better implementable in new developments or redevelopments. This research will focus on one of the stumbling blocks in this process, namely the contradiction that adaptability is not yet motivating financially, while theory says that it certainly has financial benefits in the long term. **The goal of this research is to make the financial benefits of adaptability visible and workable.** Yet there is more than financial incentivization, and that is the willingness and intrinsic motivation to contribute to a durable environment. This subject goes further than the topic of finance, but it will stimulate the take-up in practice and adaptability will become more popular when adaptability can be shown in the business case.

In the end, the larger goal is to contribute to the decrease of vacancy of tall office buildings in the future. In addition it aims to maximize the value of resources that are already invested in the current stock, and to decrease the usage of resources and the emission of CO_2 for the future developments.

Dissemination and audiences
The results of this research will be most interesting to long-term owners of the adaptable tall buildings, namely development and investment organizations. It is for them that this research strives to raise awareness, understanding and create incentives for adaptability possibilities. Yet the whole building industry may benefit from this research, since the long-term owner will be the initiator of a project that will lead to employment opportunities for all. In addition, municipalities may benefit from this research since they may adapt policies upon the gained outcomes of this research. Lastly, the research may be interesting for researchers in the field of tall building economy and financial real estate models as new input or for follow-up research.

Personal study targets
With this graduation thesis, I would like to exploit this opportunity to improve my professional skills. Therefore a couple of personal goals have been formulated, as listed below:

- To conduct scientific research within my own capabilities and skills, with some guidance but not too much. Decision-making is ought to become an important skill in the future career path, so this process of writing an individual thesis can help in evolving this skill.
- Maintaining a sense of self-confidence during my research, not questioning my own competences.
- Utilizing my current skills most optimally and be given the opportunity to expand my skills in comprehending new knowledge (and creating new links), as well as in scientific writing and explorative research. Most important here is to challenge my critical thinking and analysing skills.
- Being aware of where my weaknesses lie within the process and tackle them by turning them into opportunities.

1.5.2 Research plan

This graduation has started in September 2020 and is finalized in June 2021. The research has been divided in 5 phases, complemented in each phase by a report and presentation of the findings thus far as deliverables (figure 2; table 2). In all phases the findings have been evaluated and supplemented with the following steps of the research process until the next evaluation moment. The P5 report is the final report covering the whole research.

This research strives to gain insights and deliver conditions under which it is possible to improve a business case in a more circular manner. These conditions that are based on scientific research can then be applied in practice by initiators of a development in reconstructing their own financial models. In order to achieve this, a literature research combined with a case study has been executed. During the literature research a theoretical framework of the current knowledge has been provided. In the empirical part, a case study has been executed by detailed cross-case analysis and interviews. Thereafter a set of conditions has been formulated that can be easily implemented in practice to enhance the circular approach in a business case for an adaptable tall building.

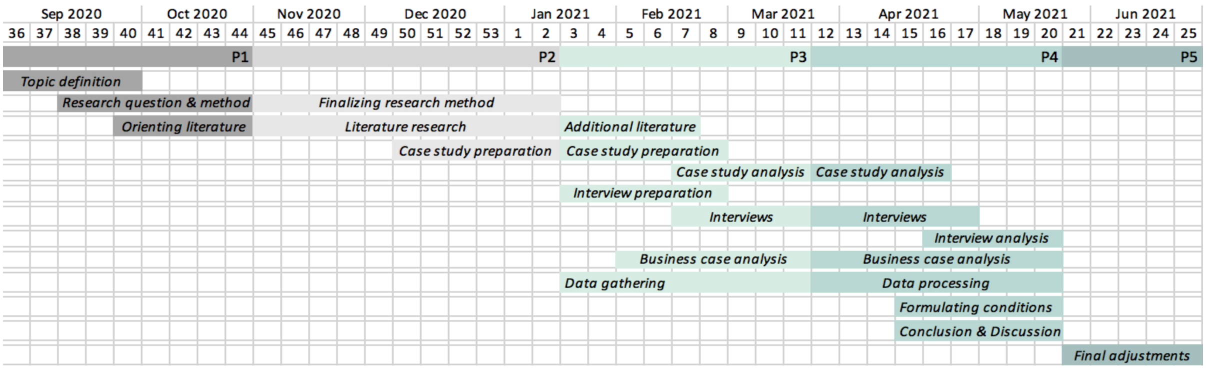


Figure 2. Planning for the research phases (own illustration).

Table 2. Overview of tasks, deliverables and milestones.

	Tasks	Deliverables	Milestones
P1	Topic definition Formulate problem statement, relevance, research method and goal and research questions	P1 report (as draft version for P2 report)	Introduction, topic and problem statement
P2	Final version of problem statement, relevance research method and goal and research questions Literature research Conditions for empirical part	P2 report Introduction and literature research	Theoretical framework and methodology
P3	Add literature (if needed) Case study: - Search for appropriate cases - Gather data - Start analysis Interviews: - Make contact and preparations - Interview protocol - Start interviews	P3 report (as draft version for P4 report)	Case study findings so far
P4	Finalize case study analysis Finalize interviews Process and analyse all data	P4 report Case study and interview findings, with suggested conditions	Final thesis with conditions and conclusion

1.6 Research method

In this section, the entire research design is described and visualized in a research framework. The chosen methods are explained in detail and proper argumentations have been provided. Lastly, the approach to data management and ethical considerations have been elaborated.

1.6.1 Research parts

Since the goal of this research has been to improve the adaptability in tall buildings by improving the business case and showing their financial benefit, this thesis has become a hybrid research that starts by conducting an exploratory literature research, followed by an empirical study with case studies complemented by interviews, as can be seen in figure 3.

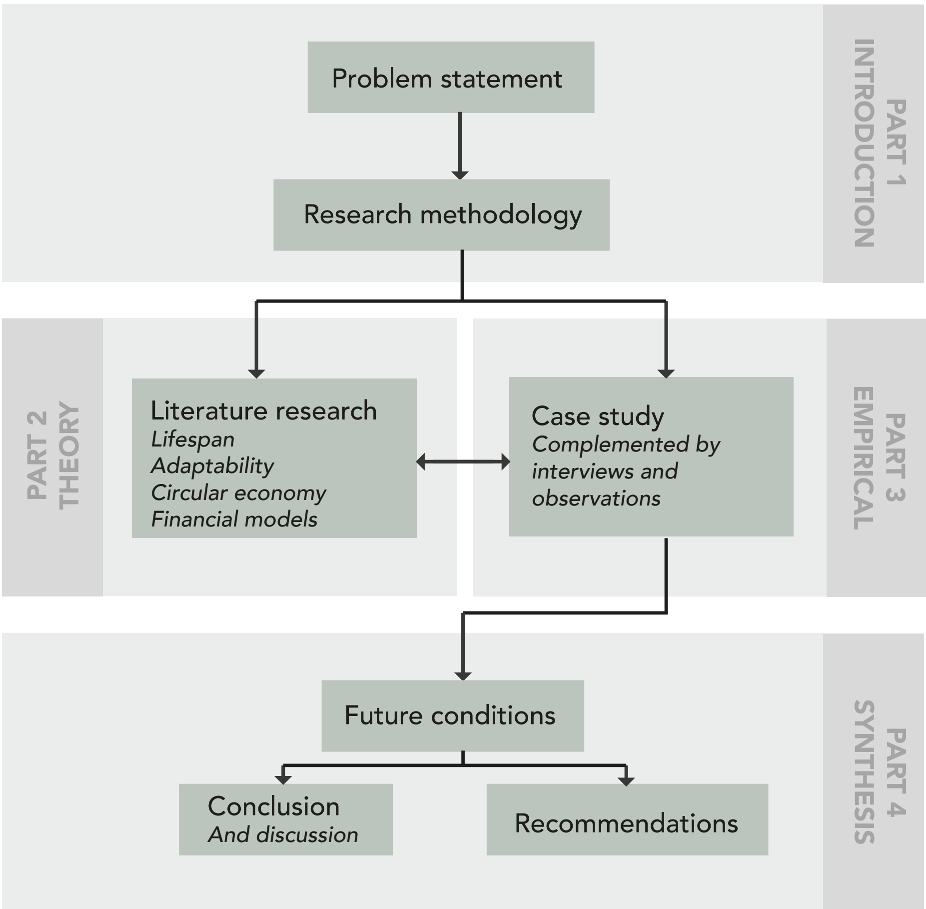


Figure 3. Research framework (own illustration).

Literature research

A literature research has been conducted to explore different terminologies, theories and definitions of adaptability, lifespan and circularity. According to Saunders et al. (2019), literature research can provide a clear framework and demarcations that may be helpful for field research. It therefore serves as a basis and starting point for the empirical part of the research. Additionally, literature research can help in adjusting the research question. This literature research has included the topics of adaptability and lifespan in the first place to identify key variables for adaptability and to create a comprehensive definition. Most important has been to identify aspects that improve the flexibility and adaptability of a tall building specifically. Those variables have been tested in the empirical part. Therefore the literature search has also considered financial and business models.

Case study
In this part, the features identified in the literature research have been tested in a case study. Learning from examples of existing buildings can be very useful in understanding the pros and cons of adaptability in a tall building, and therefore case study research has been chosen. The case study examines cases that meet certain defined conditions, to see to what extent adaptability features are already implemented or not. This degree of adaptability will be analysed by aspects found in the literature research. From the case study and interviews, findings have come forward that are critically analysed and taken into consideration with formulating an answer to the research questions.

Semi-structured interviews have been held for the retrieval of more in-depth information and insights from practice that complement the data for the case study. This qualitative information has been adopted together with an own exploration of the cases to deliver new insights and conditions for an improved adaptable business case.

1.6.2 Data collection
The way data has been collected is different for each method. For the literature research, the main keywords that have been searched on are adaptability, lifespan and circular economy. The scientific search engine Scopus has been used, accompanied by Google Scholar and the repository of TU Delft. The literature research has only focused on scientific articles and books. Financial topics have been covered for better understanding for the empirical part.

For the empirical research, data has been gathered through involved parties and semi-structured interviews. As exploration for an appropriate case, a dataset with the 225 tallest buildings in the Netherlands has been retrieved from the Council on Tall Buildings and Urban Habitat (2020b). This dataset is limited by only providing name, height, location, year of completion and function(s). Both input from the theoretical and empirical part have been used as input for the final part, which comprised of the future conditions, conclusion, discussion and recommendations.

1.6.3 Data plan
The data of the literature research has been collected mainly from the internet and several books. The data for the case study have been gathered via the graduation company and other external parties where necessary. It is important to note that this research requires sensitive data, including financial information of parties that are in general reticent about sharing such information. A data plan that describes how it will be stored has therefore been crucial. For this reason, and for the reusability of the data, the FAIR data principles have been respected (Wilkinson et al., 2016). According to the FAIR data principles, data should be (1) Findable, (2) Accessible, (3) Interoperable, and (4) Reusable. In the end, this thesis is published on the repository of the TU Delft which has free access, and it is written in English, and can therefore be regarded as consistent with the FAIR principles.

1.6.4 Ethical considerations
With conducting research, the intentions of filling a knowledge gap or creating something novel are often good, but they can have unintended negative consequences. According to Diemer & Crandall (1978), ethical principles revolve around the following four main areas:
(1) whether there is harm to participants;
(2) whether there is a lack of informed consent;
(3) whether there is an invasion of privacy;
(4) whether deception is involved.

The first consideration is protected by retaining identity information and recordings of the interview and maintain them as confidential to ensure anonymity and privacy. For the interviews, an information sheet has been created which explains the research goal, some general information and how the data will be processed. This has been complemented by a consent form that was asked to be signed by the interviewee. This consent form, which is enclosed in Appendix A, is important to minimize the risk of the second consideration. The third consideration is closely related to the notion of informed consent, because to a certain extent, the interviewee "acknowledges that the right to privacy has been surrendered for that limited domain" (Bryman, 2012). Lastly, deception is caused when work is represented as other than it is. It is for this notion that the interviews have been recorded.

II.
Literature and market research

II. Literature and market research

The ways in which buildings are designed are key to how they can be used, their impacts on the surrounding area and how long they remain fit for purpose. This chapter will elaborate on the definition and concepts around lifespan, followed by approaches, principles and attributes on achieving increased adaptability and a circular economy in the built environment.

2.1 Lifespan

A building's lifecycle can be seen as a cyclical process. It starts with the initial phase where the building is initiated, designed and constructed. After that the building can be used and managed. During the cyclical lifespan, after each use phase, the building is assessed and either obsolescence or occupation may occur. Obsolescence or vacancy can occur because the functional or technical requirements are not met, or because the costs of occupation exceed the benefits of occupation (economical obsolescence) (Wilkinson et al., 2014). With each assessment, there lies a choice to extend the lifespan or to end the lifespan of the building.

There are several underlying aspects for this choice to take into account. Blakstad (2001) distinguishes them into hard and soft values. Soft values are difficult to measure, since they consider the love, appreciation and emotional value for a building and the willingness to keep it. The hard values associated with location, market and the building are better quantifiable and can be separated by value to the owner and to the user respectively (figure 4). The decisive factor is the building itself, specifically its technical and functional quality, as these influence the financial feasibility of both the user and the owner.

The lifespan of a building is an estimation of time. The estimations vary across countries and depend on functional requirements, materials, geographic and climate conditions (De Jong & Wamelink, n.d.). Most of the time a lifespan of 50 years is used, but this can be higher for dwellings and lower for offices.

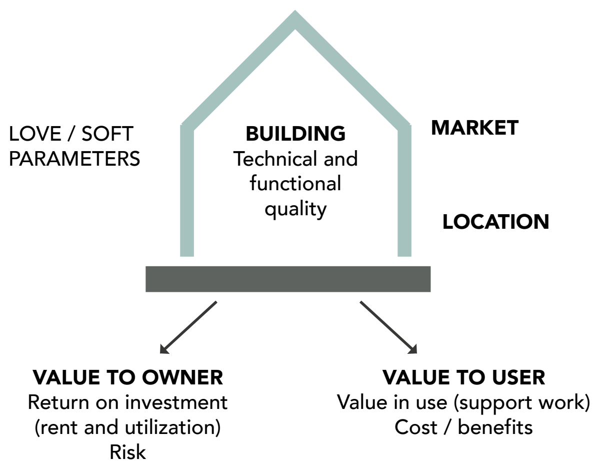


Figure 4. Important decision values from Blakstad (2001)

A problem with a short lifespan however is that opportunities are missed since the project is most likely continued for its determined lifespan together with the consecutive financial calculations leading to a “go” for the project. The research of De Jong & Wamelink (n.d.) appeals for the use of 200 years as lifespan, because 50 years is simply too short for a durable building that allows multiple uses in a lifespan. Marsh (2017) agrees on that fact but states that an average building lifespan of around 100 years would be more accurate looking at the changing social and functional factors in a European context.

The lifespan of a building often differs from the lifespan of the separate elements. The following paragraphs elaborate on different approaches towards the layering of a building.

Frank Duffy

A widely known concept of building in layers was first proposed by Frank Duffy (1990). He states that buildings should be seen as a collection of components with different life-cycle durations. He defined three distinctive building layers in office buildings, which are the shell, services and scenery (figure 5). The latter refers to everything that is adaptable without influencing the performance of the services or shell, and has a duration of 5 years or less. The services include electricity, ventilation, sewerage and other servicing installations such as elevators, and last for approximately 15 years. Lastly, the shell is defined by the building facade and the construction and can last 50 years.

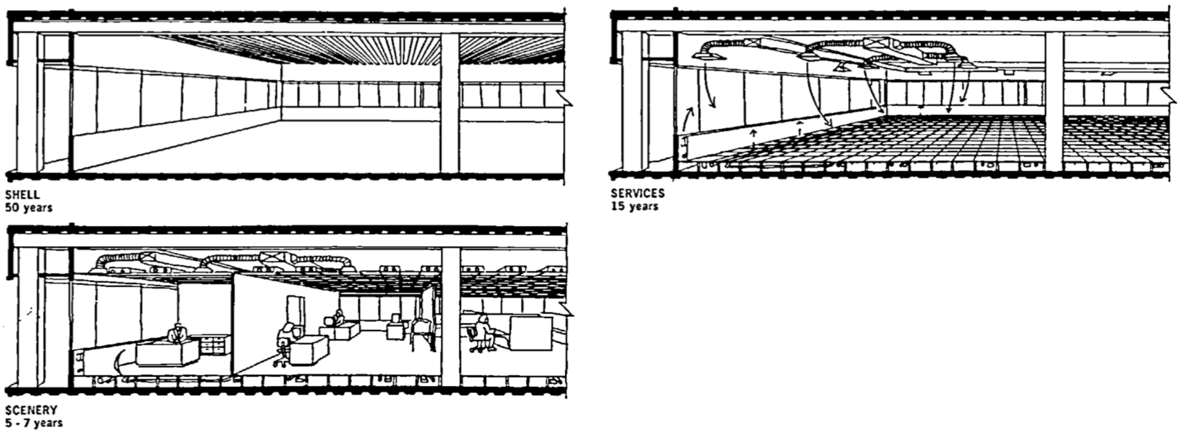


Figure 5. The three layers Shell, Services and Scenery defined by Duffy (1990)

Stewart Brand

Stewart Brand (1994) later adapted Duffy’s approach, which he called the shearing layers of a building (figure 6). It demonstrates a building in layers that allows for replacement of elements with shorter lifespans while longer-lasting elements remain in use. All layers are adjustable and demountable in their own and in relation to each other. Therefore it is required to not enclose short lifespan elements with longer lifespan elements. Connections between different layers can obstruct the adaptation by increased costs and complexity. Also, it is important to maximize the durability of the structure, where the required lifespan is the longest which therefore has the largest impact. There is also a certain hierarchy in the layers, where the lowest layers are the most easily changed, while the structure is the most difficult to change after initial construction. Thus the lifespan of the structure inherently determines the overall lifespan of the building. This leads to independence of elements, which is a key principle for achieving adaptability. Independency allows for elements to be removed or upgraded without affecting the performance of the other elements (Russell & Moffatt, 2001). It facilitates recycling, reuse and remanufacturing (ARUP & Ellen MacArthur Foundation, 2020). Because each layer is composed of different elements, possibly with different lifespans themselves, the lifespan per layer may not be as straightforward as sometimes suggested.

Brand (1994) defines the site as eternal, yet the conditions around the site such as infrastructural and cultural aspects can have an impact on the building's functional lifespan. Vacancy can also be a result of other location-related developments, such as the image of the location, or changing site values (Remøy, 2010).

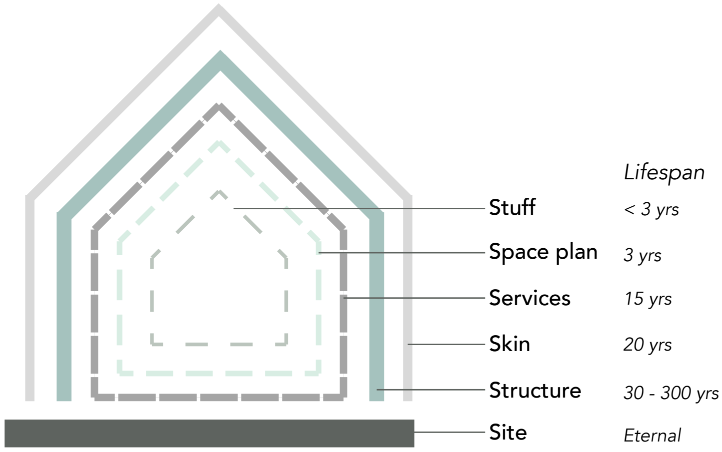


Figure 6. The six layers of a building according to Stewart Brand (1994).

De Jonge (2000) takes another approach on the lifespan of buildings by making a distinction between the technical, functional and economic lifespan respectively. Here the technical lifespan indicates the period in which the real estate object can deliver the technical and structural performances that are necessary to be able to use the building and to guarantee the safety and health of the users. The functional lifespan is the period of time during which a real estate object complies with the functional demands of the user. This differs per specific user of a building. In the shearing layers approach of Brand (1994), it is interpreted that the functional lifespan represents the stuff and space plan and the technical lifespan represents services, skin, structure and site. It is the economic lifespan that has not been taken into account here. The economic lifespan is determined by the period in which the present value of all future incomes is higher than the present value of all future expenditures (Wilkinson et al., 2014). The economic lifespan is a perception of value and the estimation is influenced by tax regulations, legal requirements and accounting standards (Kohler & Yang, 2007).

The research of Remøy (2010) mentions that the lifespan of buildings is determined by financial, functional, technical, cultural and legal aspects. Often, the three types of lifespan have an influence on each other. If the functional lifespan ends, for example because of technological advancements or changes in the user's requirements, it also means the end of the economic lifespan. Because of the supply and availability of newer offices, the functional lifespan of offices has decreased. Yet if the building becomes functionally obsolete, it does not always mean that the building is technically obsolete. The building may function well enough technically, which leads to a mismatch between the building's functional and technical lifespan. This causes structural vacancy, and finally the end of the economic lifespan. By increasing the functional lifespan or decreasing the technical lifespan, the gap can be closed and structural vacancy can be avoided.

Van den Dobbelsteen (2004) suggested the addition of a fourth lifespan, which is the environmental lifespan. This is defined as *"The time-span after which demolition and reconstruction becomes environmentally more favourable than renovation and re-use. This lifespan is therefore similar to the economic lifespan, yet with the environmental load instead of actual costs as a decisive criterion."* This fourth type is different from the other three by the fact that it is not directly visible from the building to neither owner nor user, and therefore it is easily forgotten. It also remains uncertain whether the end of the environmental lifespan leads to vacancy. Yet with the growing attention and regulations on sustainable buildings, this might become the case in the future.

As Geraedts (2008) formulated it, *"without adaptability buildings will reach the limit of their functionality or efficiency much sooner than their expected life cycle"*. Adaptability can therefore be seen as a tool for achieving a more durable real estate stock. Manewa (2012) supports this by stating that the economic lifespan can be best extended by adaptation, rather than just maintenance. Thus, *"adaptable buildings provide economically sound benefits over the long term"* (Manewa, 2012).

Many practitioners in the building sector believe that longevity of the building is related to the structural material. Often the "durable" materials steel and concrete are regarded as providing the longest service life, while wood has the shortest life expectancy. However, the research of O'Connor (2004) showed that most buildings are demolished for other reasons than the physical state of their structural systems, and their structures were not at the end of their technical lifespan. It was mainly the lack of maintenance of non-structural elements that led to the end of a functional lifespan, and it shows that functional lifespan is often considered over the technical lifespan in demolish or redevelopment decisions.

2.2 Adaptability

Buildings with a long lifespan are durable buildings, and therefore, durability is an aspect of sustainability (Remøy, 2010). Yet sometimes the fitness for use has decreased, and that means the end of the functional lifespan. If the technical lifespan has not reached its end, the decision for either selling, demolishing, adapting or transforming the building can be made. This paragraph starts with a definition of what adaptability is, after which different theories are discussed. Thereafter an elaboration on characteristics that influence the adaptability of a tall building has been given. Lastly, evidence against adaptability and possible obstacles have been mentioned.

Definition

There are various definitions of adaptability used in the current literature, yet Schmidt et al. (2014) defined four characteristics that are expressed in almost all definitions of adaptability. The first one is the *"capacity to accommodate change"*, where a distinction can be made in internal or external change. The second characteristic is the ability to *"remain fit for purpose"* or *"reduced mismatches"* between the building and space supply, and the user's needs and demands. The third theme is related to value; here different definitions can be used, such as *"maximising its productive use"*, *"to fit both the context of a system's use and its stakeholders' desires"*, while *"at a minimum cost"*. The last characteristic is time; the lifespan is extended, it is often about long-term changes, and time relates to the speed of change. Since Schmidt et al. (2014) succeeded in determining the most important aspects of adaptability, this thesis adopts his definition of adaptability, which is

"the capacity of a building to accommodate effectively the evolving demands of its context, thus maximising its value through life"

Adaptability and flexibility are not the goal but rather the means to an end, and instrumental in generating quality and adding value or saving costs (Geldermans, 2016). Here the circular economy is an end, but the current industry is still geared towards a linear economy. Adaptability can therefore be regarded as a condition for circularity and a circular built environment.

Flexibility
Flexibility is a concept often used together and sometimes interchangeably with adaptability. If a building is able to adapt, the building is also flexible. In the literature adaptability and flexibility are both used since they show some overlap, yet some researchers have attempted to point out the differences. According to Estaji (2017), *"researchers and architects use "flexible" for physical changes and "adaptable" for non-physical changes. Adaptability as capable of different social uses and flexibility as capable of different physical arrangements"*. On the other hand, Blakstad (2001) mentions that adaptability has a top-down approach, while flexibility is considered as changes from bottom-up. Here flexibility stands for changes within a limited set of possibilities, while adaptability has the capacity to answer to unexpected changes by interventions in the building. Flexibility can be interpreted as allowing changes within a building, and adaptability goes one step further in allowing changes by adapting the building. A third distinction that can be made is based on the aspect of time; flexibility is often described as short-term while adaptability refers to long-term, and larger changes (Pinder et al., 2017). Besides, flexibility is always presented as needing less energy, money and efforts.

Adaptability allows modification of one element without affecting the others, and this requires high quality design. Adaptability can be seen as a means to extend the building lifespan, and serves therefore as a contribution to a more sustainable built environment. In addition, adaptable real estate is more resilient for financial downturns and obsolescence (Schenk, 2009). Consequently this prevents structural vacancy to a certain extent (Remøy, 2010). From a social perspective, adaptability can give a second chance to neighbourhoods with high criminal rates or a negative image (Kougea, 2019). This prevents that the value of an area will decrease over time. Lastly, adaptability or transformation maintains the current urban fabric by reusing the structure (Aytac et al., 2016).

Open Building
Adaptability in the built environment has been studied by many architects and researchers. John Habraken was one of the first, by publishing his book called *"De dragers van de mensen"* in 1961. In this book he states that housing is not completed by the developer or the constructor, but it offers a structural system in which the owner or occupier may choose the finishing elements. He illustrates adaptability as a phenomenon that gave tenants the possibility to influence the design of their own dwelling. By distinguishing the so-called drager and inbouw (support and infill), a distinction was made between the collective and the individual, as well as the short and long lifespan, and the fixed and variable (table 3). This view was progressive for the practice of that time, and his legacy has been built on further under the name of Open Building nowadays. Open Building in principle means the building leaves modifications open, with no boundaries, and can thus be regarded as future-proof. An important prerequisite for this is an architecturally interesting support, so that people want to occupy the building even after its first use. Open Building however has not been implemented to a large extent yet, mainly because there is still little supply in flexible building elements. In addition, there often remains a distance between client and user of the building, which obstructs the process of co-creation in Open Building.

Table 3. Distinction of Drager & Inbouw as defined by Habraken (1961)

	Support	**Infill**
Duration	Long lifespan, fixed	Short lifespan, variable
Scope	Structure and skin. Also collective spaces, entrances, building corridor.	Services, space plan and stuff. Inner walls, toilets and furnishings.
Determined by	Owner; architect/constructor	User (could be owner)

IFD
The ideas of IFD building are taking a different perspective on sustainable and adaptable buildings. IFD stands for Industrial, Flexible and Demountable buildings. With this approach, the building parts will be manufactured industrially and assembled on site, and it allows flexibility in use and at the end of its lifespan disassembly instead of demolition (Remøy, 2010). With IFD the building's technical lifespan is adapted to the functional and economic lifespan, making the technical lifespan deliberately shorter than usual. This approach is in contrast with the previous approaches on building layers, in which there is often a permanent structure with a very long lifespan, and the other layers can adapt whenever desired.

Feasibility of adaptability
The feasibility of a transformation is highly dependable on aspects within a broader scope. For his graduation thesis at the TU Delft, Schenk (2009) analysed the feasibility of office transformation into dwellings, and he elaborated his thesis based on four different aspects: legal feasibility, technical feasibility, financial feasibility and commercial feasibility. The following paragraphs will take a similar division.

Since his thesis is comprehensive in the office transformation field, the findings of Schenk (2009) that also relate to tall buildings have been summarized below, complemented with findings from the Toolkit[1], a document established by RE:BORN with principles for their redevelopments, as well as by own findings.

Legal feasibility
The feasibility for an adaptable building starts with the legal requirements. In the Netherlands, each location or plot has a land-use plan determined by the municipality that states the allowed functions, maximum building heights, and others. The exact powers that a municipality has to control future developments are laid down in article 3.1 of the 2006 Spatial Planning Act (Hobma & Jong, 2016). The redevelopment possibilities, but also the economic value of the plot, are therefore dependent on the land-use plan. It is possible to apply for a change of land-use plan, but the municipality may also choose to adopt for multiple land-uses to be allowed. Two different functions can then be combined at the same time, such as retail on ground floor with dwellings on top, but it also allows one function after another, as is the case with transformation. It is important to involve the municipality in the earlier phases of the development already and enthuse them for the adaptability possibilities, so that cooperation for flexibility concerning the land-use plan will be achieved. Yet tall buildings are often mixed-use, which means they already possess a favourable land-use plan that allows multiple functions. This limits the risk of the market dynamics in for example office, hotel or residential sectors.

A second legal obligation to comply with in the Netherlands is the Building Decree. In accordance with the 2012 Building Decree, municipalities assess the building for requirements in safety, health, usability, energy efficiency and the environment (Ministerie van Algemene Zaken, 2017). If a developer wants to develop a tall building that is able to adapt, the requirements for different functions need to be taken into account. This can lead to stricter requirements than necessary for the first function, but they have to be included in the brief already for transformation to be possible.

Technical feasibility
Every building is different and therefore needs tailored interventions, however for offices there are generally two typologies that are frequently used. The first one is the single corridor type. This typology consists of a horizontal corridor that is centrally located and surrounded by the office spaces. The structure is based on hollow-core floor slabs, which are load-bearing in one

[1] Internal document of RE:BORN, not publicly available.

direction, complemented by a load-bearing facade. The single corridor type is often used for buildings until 12 floors. The second typology is the central core tower type. This type is often used for tall buildings until 50 floors and offers the highest flexibility. The following paragraphs elaborate on the technical characteristics and have been divided into the shearing layers of Brand (1994).

Structure: It is important to design the structure as columns with preferably free floors or with large grid measurements to maximize the freedom for the space plan layout. If columns are needed, a column grid of 1,8 m is preferred. The central core of this typology contains the vertical (emergency) accesses. The length of the span from core to facade is relatively small, since maximums of room depth for the incidence of daylight have to be met. Often a depth from facade till core of 5,4 m, 7,2 m or 9,0 m is used (Schenk, 2009; REBORN, 2020). This small span allows the usage of wide floor slabs which are load-bearing in two directions. This creates maximum freedom in floorspace layout. In addition, wide floor slabs allow shafts to be made afterwards for the additional service channels needed for dwellings, which is a great benefit. If the floor would be load-bearing in one direction, additional interventions would be needed, leading to higher costs.

The required floor-to-floor height of offices lies higher than for dwellings (3,6 m compared to 3,0 m), which results in little additional costs. In fact, the additional 0,6 m can be regarded as an additional quality in dwellings that one rarely finds in new developments with their traditional budget cuts. It is also important to incorporate in the design phase the possibilities for horizontal floor extensions, as well as extra floors on top that the construction and foundation are able to support.

Lastly, the structure needs to be fire resistant for 120 minutes for dwellings and 90 minutes for offices. Schenk (2009) showed with a calculation model that with little additional costs the 120 minutes can be easily achieved.

Skin: The facade and its characteristics influence the transformation possibilities significantly. The facade is often the most costly aspect in new developments and transformations (Mackay, 2008). Therefore it is advised to design the facade as demountable and adaptable, to contribute to some extent to the overall feasibility when adaptations are needed. Adaptations are most of the time needed since requirements for thermal and acoustic insulations are often stricter for residential purposes than offices (Remøy, 2010). A distinction can be made between the long-cyclical facade and the short-cyclical facade (REBORN, 2020). A long-cyclical facade is in accordance with the grid structure, and it is the architectonic, high-quality part that determines the identity of the building (figure 7). In contrast, a short-cyclical facade is located in-between the grid structure, and is only focused on the first function. This means in terms of glazing and frames it must be able to adapt. The most frequently used type of facade in the Dutch tall office buildings is the non-load-bearing curtain wall (Schenk, 2009).

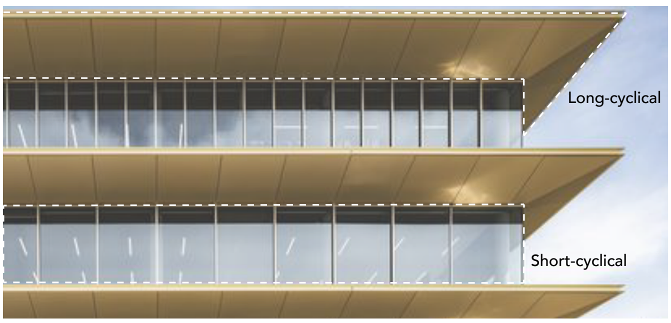


Figure 7. Distinction between different skin elements (own illustration)

Services: In the central core tower type, the services are located in the core. Since services have a short lifespan of around 15 years and services are function-specific, it is not obvious to consider a multifunctional, adaptable system, but rather to replace it when needed. Built-in facilities to anticipate on future functions are not advisable, since there is a possibility that those (high-cost) facilities will never be used. Besides, innovations occur in such a fast pace that recent innovations could become outdated in a couple of years already, or built-in facilities are not suitable to implement those innovations.

With a transformation to dwellings, services will need extensive replacement since there are more "wet cells" (bathroom, kitchen, toilet), and horizontal channels need replacement since they would puncture the dwelling partitions that come in place. Therefore services should never be integrated with the structure, but it is advised to maintain some degree of flexibility within their elements (for example demountable, adaptable and decentral). Nevertheless the costs of replacing the services are always quite high (Mackay, 2008).

Financial feasibility

The research of Schenk (2009) showed that a central core building is already adaptable in its standard construction. This makes the central core tower type the most favourable typology to transform, both from a technical and financial perspective. Only the skin and services will influence the financial feasibility.

Johnson (1996) suggests that the time needed for transformation is typically 50% - 75% of the time necessary for demolition and new construction of the same floor area. This shorter development period lowers the cost of financing and the effect of inflation on the construction costs. So for organisations that do not wish to relocate can have less disruption to their operations and cash flows, reducing temporary accommodation expenses as well (Langston et al., 2008). Beside the time benefits there is also the costs of converting, which are lower compared to new construction since part of the structure and elements are already in place. The research of Shipley, Utz & Parsons (2006) interviewed developers that state that construction costs can be cut by as much as 22% by using existing buildings. Van der Voordt (1990) states the following: *'If the design has been well formulated, adaptable building need not be much more costly than non-adaptable building'*. Yet on the other hand it was reported that some transformations can cost twice that of new buildings, and therefore it remains property-specific.

Commercial feasibility

The commercial feasibility differs from the financial feasibility in focusing on the support base and possible demand from the market. Adaptability to dwellings is only commercially feasible on locations where people want to live. In the Netherlands, 70% of vacant offices are located in monofunctional office areas (Remøy & de Jonge, 2009). Transformation will only be possible here if the larger urban area will be redeveloped as well. The characteristics of both location and building in a monofunctional area are often only focused on that particular function, which makes transformation to for example housing less attractive and unfeasible. Van der Voordt et al. (2007) conducted a study that showed that out of 187 transformations from office to dwellings, only 4 cases were located outside the inner-city. This shows the importance of location and especially the attractiveness of inner-city redevelopment.

Literature against adaptability

Adaptation projects can prove to be unsuccessful due to the following drawbacks as mentioned by Douglas (2006):

- **Functional:** There is no guarantee that an adapted building will meet the performance of a newly built building. Since restrictions in the current form, layout and heights may have already been determined, it may necessitate compromises from the user, hence being second best.

- **Technical:** There is no guarantee that the adaptation efforts will overcome all the deficiencies in the performance; especially with older building this becomes demanding. In addition, the lifespan of an adapted building will be extended roughly by about half of that for a new building.
- **Economic:** The maintenance costs for an old building, even after refurbishments, are usually still higher than new buildings. Secondly, the rental income that can be derived from an adaptable building may not be as high as the rental income obtained from a new, modern building that fully meets the demands from the user (without compromises being made).
- **Legal:** For older properties it may be difficult to achieve full compliance with building regulations.

In addition, Manewa (2012) mentions the following challenges with adaptability that still prevail:

- Ignorance by the client and lack of awareness of future costs (e.g. maintenance costs and cost of adaptation).
- The complex and theoretical relationship between money now and money spent or received in the future.
- High number of unpredictable variables used in the calculation.

Despite the benefits that adaptability can provide, there is still a slow up-take in the construction sector. Some authors ascribed this slow up-take to the 'circle of blame' as illustrated by RICS (2008) in figure 8. It illustrates the different perspectives and incentives among stakeholders, and how they blame each other for the failure to adopt sustainability in building (re) developments. Constructors do not make more sustainable buildings because they claim that developers do not want them, while developers claim that investors are unwilling to fund them because there is no demand from occupiers. Moreover, the report of RICS (2008) also claimed that the circle could have been broken by the end users' demands, as the markets are usually tenant-driven. It advocates *"to involve a wider circle of actors to create "Virtuous Loops of Feedback and Adaptation" within the market as well as a radical rethinking in terms of marketing and communication"* (RICS, 2008) (figure 9).

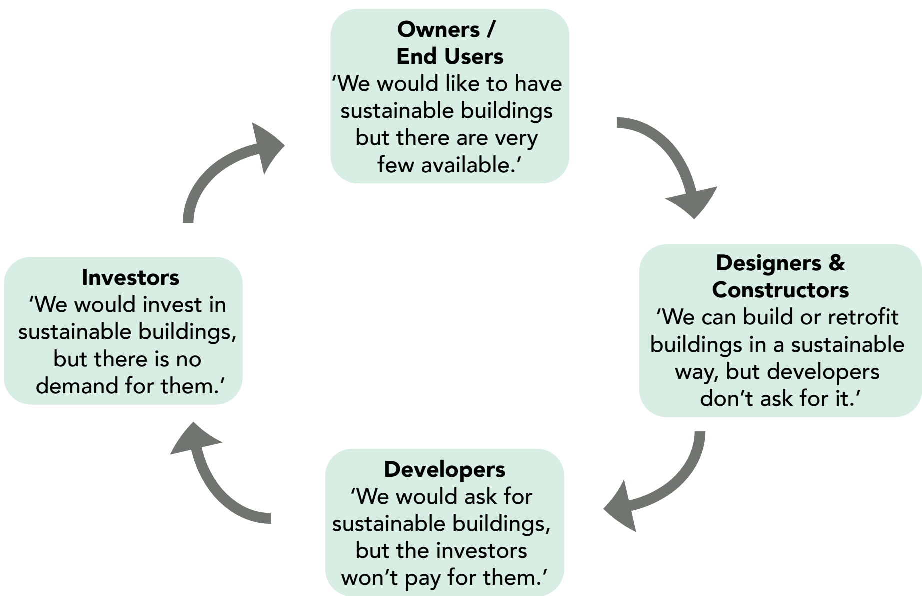


Figure 8. The Vicious Circle of Blame (Adopted from RICS, 2008)

The realignment of incentives is crucial for breaking the vicious circle of blame. So-called feedback mechanisms would need to be fully put in place to facilitate change. In addition, the author states that *"finance and valuation processes play a pivotal role for demonstrating value to clients"* (RICS, 2008). An owner or occupier can largely be persuaded by seeing the added value in the calculations by valuation professionals. This "error" is of growing importance to investors as well, as lease terms have shorten and therefore reletting the object becomes a more critical issue (Ellison & Sayce, 2007). Besides, banks could also influence the investor and occupier by lending at more favourable rates since adaptable buildings can be seen as less risky (Pinder et al., 2011).

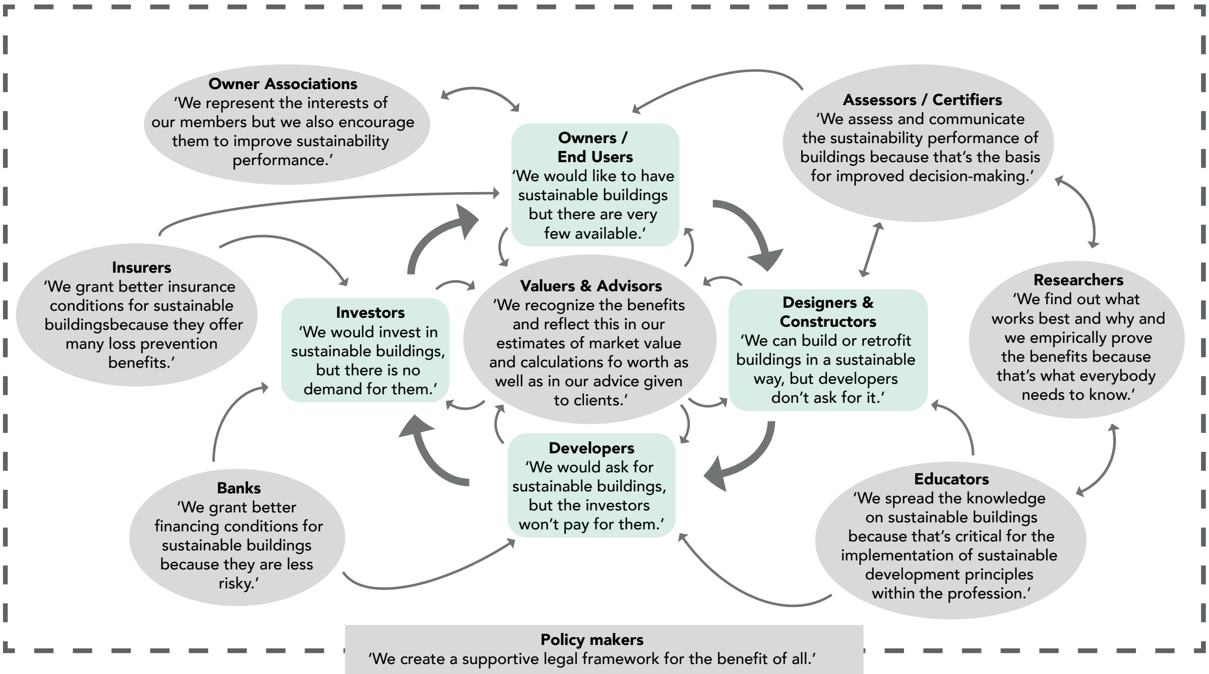


Figure 9. Virtuous Loops of Feedback and Adaptation (Adopted from RICS, 2008)

The degree of an adaptable design that is implemented in the existing building is of critical importance (Remøy, 2010). Therefore it is important to consider adaptability aspects already in the design phase. Sometimes the new function fits less optimal in the existing building, yet the emotional and historic values of existing buildings may overcome this. Those can be main drivers to be interested in the transformation, even though the revenues are lower than for new developments. After all it should be financially feasible, and the contribution by preserving the historic values should be taken into account here as well.

Yet the investor needs to be willing to invest a higher amount of development costs if adaptability is enhanced, and this willingness depends mostly on the investor's perceived benefits of the extended technical, functional and economic lifespan compared to the additional costs. The benefits of adaptability are not important for the first user, and he is therefore not willing to pay for it. The benefits will come forward after the first use, and it will depend on whether functional changes are needed or not. With adaptable buildings, the investor must be willing to invest for the long-term. By the adaptability measures mentioned above, the main goal is to extend the lifespan. This means the investment period will be longer.

2.3 Circular economy

The circular economy is designed with the aim to extend the life of products as long as possible, with having the highest value possible (Circle Economy, 2019). It differs from the linear economy in setting two additional value creators besides economic value, namely environmental and social value. The Ellen MacArthur Foundation has defined three principles that are fundamental for a Circular Economy, which are the following:

*"**Design out waste**: waste does not exist when the biological and technical components (or 'nutrients') of a product are designed by intention to fit within a biological or technical materials cycle, designed for disassembly and refurbishment."* (Ellen MacArthur Foundation, 2013)

*"**Build resilience through diversity**: modularity, versatility, and adaptively are prized features that need to be prioritized in an uncertain and fast-evolving world."* (Ellen MacArthur Foundation, 2013)

*"**Think in 'systems'**: the ability to understand how parts influence one another within a whole, and the relationship of the whole to the parts is crucial."*(Ellen MacArthur Foundation, 2013)

The three principles can be derived back to the circular thinking, flexibility, adaptability, and the thinking in layers like Brand (1994) and Duffy (1990). Especially their independence is crucial for future use which makes disassembly inherent to a circular economy. To design out waste, disassembly of products is needed, or materials should be kept in the building for as long as possible to make disassembly unnecessary or delayable. Disassembly allows for harvesting products, elements or materials. The more a building is composed of demountable elements, the easier the harvesting process will be and the more common it will become. Therefore demountability is at the heart of enabling a circular economy. Figure 10 shows other factors that influence the reusability of an element.

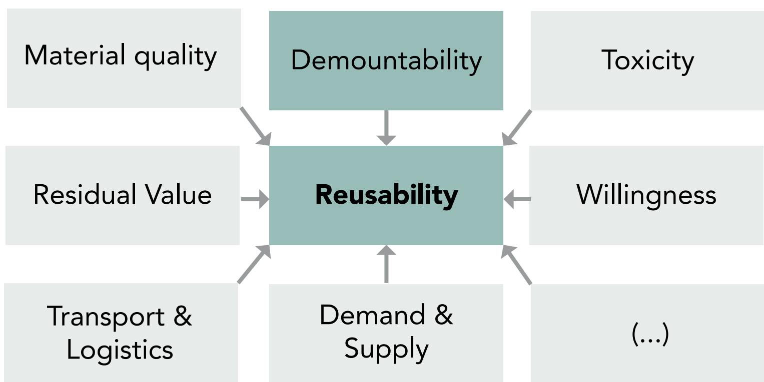


Figure 10. Demountability as factor for reusability (Adopted from Van Vliet, 2018)

All in all, there are different strategies or actions towards reducing of the usage of materials and resources. The different strategies are also known as the 10 R's or the R-ladder (Potting et al., 2016). The higher located on the ladder, the more circular the strategy is, as can be seen in table 4.

Table 4. The 10 R's (Potting et al., 2016)

	Strategy	
Use and produce the product smarter	R-0 Refuse	Make a product redundant by getting rid of its function, or whether it can be delivered by a radically different product.
	R-1 Rethink	Intensify product usage (for example by sharing products, or multifunctional products).
	R-2 Reduce	Produce the product more efficiently by using less resources and materials, or in the usage of it.
Extend the lifespan of product and elements	R-3 Re-use	Reuse of discarded but still good product in the same function by another user.
	R-4 Repair	Repair and maintenance of broken product to use in its original function.
	R-5 Refurbish	Refurbish and modernize the original product.
	R-6 Remanufacture	Use parts of discarded product in new product with the same function.
	R-7 Repurpose	Use discarded product or parts thereof in new product with different function.
Useful application of materials	R-8 Recycle	Process materials into the same or inferior quality.
	R-9 Recover	Incineration of materials with energy recovery.

In addition, a circular economy allows feedback loops of materials that are retracted and reinserted back into the economy (Ellen MacArthur Foundation, 2013). Value is best maintained if reuse is possible on the element level (e.g. boiler); if that is not possible, it is interesting to reuse products (e.g. pipes). The last option is to reuse materials (e.g. recycled metal). A circular economy can be achieved by looking at the technical side, the process and the finances in a building development process, as can be seen in the IPF-model of Van Oppen (2017) in figure 11. This paragraph will elaborate on all three fields; First by discussing Total cost of Ownership and Circular Economy as financial approaches, after which the Building Circularity Index concerning the technical side will be elaborated, and lastly a new business model as part of process will be discussed.

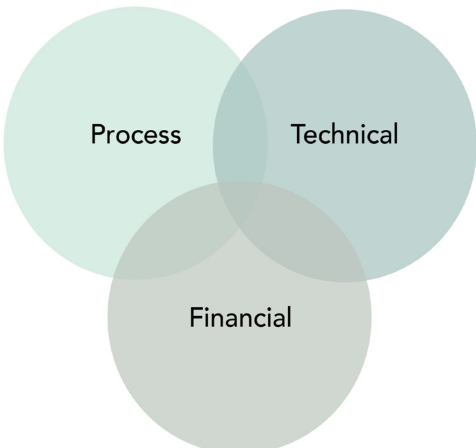


Figure 11. IPF-model for enabling a circular economy (Van Oppen, 2017).

2.3.1 Life Cycle Costing & Total cost of Ownership

Within a circular economy, Life Cycle Costing (LCC) answers to the need for a cost approach to learn the total costs and benefits of real estate objects throughout the whole lifecycle. Different terminologies have been used, including 'total life costing', 'lifecycle costing', 'total cost of ownership' and 'whole life cycle costing'. Lifecycle costing is defined as *''a tool/ technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement costs, through to end of life"* (ISO 15686-5, 2017). An example can be to invest in solar panels, which leads to a higher initial investment, but since it generates energy it will lead to lower energy costs in the operational phase. Therefore the total life of buildings must be considered. LCC can also be used to forecast and evaluate planned capital expenditures to ensure the optimum value by considering all future costs and benefits calculated back to present values. The different cost components are divided as seen in figure 12.

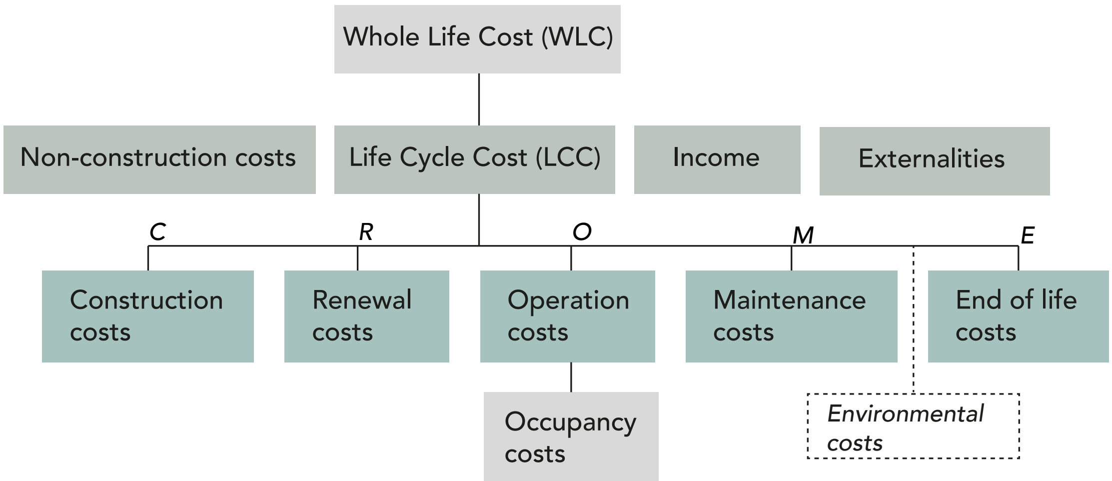


Figure 12. Schematic overview of elements of whole lifecycle costs (RICS, 2016)

Lifecycle costing (LCC) and total cost of ownership (TCO) are used interchangeably, and although some researchers consider it as equals, others suggest there is a modest difference. According to Barbusova et al. (2019), the TCO takes into account the total life cycle costs after its purchase by an organization. It therefore provides the total costs of the product from a customer's perspective. On the contrary, LCC considers the building costs from initial construction until demolition, which is equal to the whole technical lifespan, whereas the TCO can be regarded as determining the costs for an economic lifespan. With these definitions, it sometimes occurs that the LCC and TCO are actually the same; the moment of purchase happens before construction and therefore it holds the total technical lifespan as well. This explains the confusion about both terminologies. Yet from here on this research continues with using Total Cost of Ownership as main terminology, as the business case considers the economic lifespan over the technical lifespan, yet taking the lifespan of elements into account.

A likely benefit of both LCC and TCO is that the final decision represents the total cost commitment of a facility, risk and performance, rather than the initial costs only (Manewa, 2012). Besides, it provides a framework which allows to compare options at all stages of the development. In comparison to traditional valuation methods, LCC and TCO often lead to more detailed results. However, it also requires substantial amounts of appropriate, reliable and relevant information and data, and this is where most of the obstacles in practice prevail (Chiurugwi et al., 2015). In addition, the construction sector adopts TCO rather slow because of lack of fiscal measures that encourage clients' use of TCO, as well as its difficulties in forecasting future costs and incomes. Another barrier for using TCO instead of traditional can be the long time period between the design phase and data becoming available on operational expenses of such a building (Neale & Wagstaff, 1985). All these things are found to be difficult to deal with by organizations, and so they tend to remain using the traditional initial capital costs types of valuation.

Table 5 provides an overview of costs taken into account with the traditional method, the Total Cost of Ownership and lastly with a full Circular Economy approach. The main distinctions lie with the operational costs, the facility costs and the cycle thinking. TCO considers investment and operational costs, but excludes energy costs as these costs are often for the user. As for life cycle costs, TCO only considers reinvestments, but excludes other additional expenses or income related to the technical lifespan of building elements. The Circular Economy approach is the most comprehensive and integral approach, and will therefore be most useful for this research.

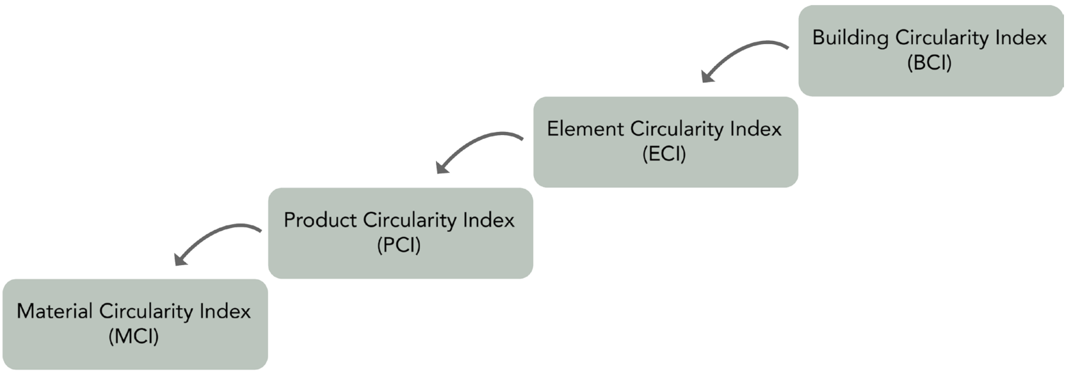
Table 5. Comparison of financial costs between three different methods (Brink groep, 2014)

	Traditional (initial investment)	**Total Cost of Ownership**	**Circular Economy**
Investment costs (NEN 2580)	X	X	X
Land costs	X	X	X
Construction costs	X	X	X
Interior costs	X	X	X
Additional costs	X	X	X
Operational costs (NEN 2632)	X	X	X
Fixed costs	X	X	X
Energy costs			X
Maintenance costs		X	X
Administrative management costs		X	X
Facility costs (NEN 2748)			X
Security			X
Interior cleaning			X
Facade cleaning			X
Life cycle costs		X	X
Life extending costs i.e. rejection, extension or rearranging flexibility			X
Reinvestments		X	X
Incomes	X	X	X
Sell / rent	X	X	X
Yield		X	X
Residual value of real estate			X
(Re)cycle thinking			X
Ecological value			X
Economical value: Upcycling, downcycling or reuse			X
Residual value on component level			X

Residual value
In the linear economy we assume that products have a negligible value at the end of their economic lives, and therefore we depreciate them to € 0. In a circular economy, where products and materials are continuously retracted and reused, there is always a residual value. The residual value is defined in this thesis as an estimated value that the asset or building element is still worth after the end of its economic lifespan. The economic lifespan has been mentioned explicitly, because often the end of the technical and functional lifespan have not been reached yet. According to research from Alba Concepts (personal communication), the reuse value after 40 years of elements can vary between -5% and 35% of the purchase price.

The residual value can be regarded as the highest possible value that can be harvested out of current real estate. This is accompanied by a shift in mindset in which more conversations are about to what extent waste may yield as input for a new product (Coalition Circular Accounting, 2020). A higher harvest value has two advantages. First, a high harvest value results in cost savings that can lead to lower production costs and periodic payments. Secondly, the harvest value can potentially serve as security for financing.

2.3.2 Building Circularity Index
A problem with the circular economy and the implementation of its principles lies at the lack of information concerning the durability and sustainability of particular materials and elements, but also for a common notion of how "sustainable" is defined and measured. For this, steps have been taken in developing instruments and measurement tools. One of them is the Building Circularity Index (BCI), a scientifically substantiated and tried-and-tested measurement tool to determine the circular potential of a building (Van Vliet, 2018). It measures to what extent the principles of the circular economy are implemented in a building project. The BCI consists of two Key Performance Indicators (KPIs), which are Material Use and Disassembly. The Building Circularity Index determines the circular potential of a building but can be broken down in the following levels:



Especially the material and product level are relevant for determining a residual value, which is why these two are elaborated. The Material Circularity Index distinguishes the origin of the material as input, the future scenario for it, and its (technical) lifespan (Van Vliet, 2018). For the input, there is looked at what percentage is either new, recycled, bio-based or re-used. After that, the most-likely future scenario is determined, with an accompanied score given to it. Lastly, a utility factor is needed, which comprises of the technical lifespan according to the layers by Brand (1994) multiplied with a the industry's average expected lifespan (figure 13). On product level, there is a level of demountability that needs to be determined for measuring the product circularity.

With the current traditional buildings that are not designed with the ideas of demountability, it is rather complex to assess the demountability of it and they probably will score very low. Besides there is little data available of the current buildings. It is therefore advised to focus on the demountability of elements that are added from now on, either in renovations or in new developments.

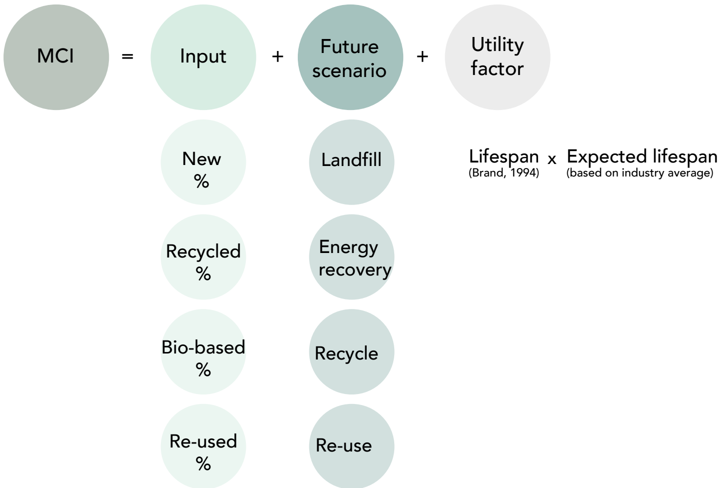


Figure 13. Material Circularity Index characteristics (adopted from Alba Concepts)

Figure 14. Product Circularity Index characteristics (adopted from Alba Concepts)

2.3.3 Circular business models

In their publication "Circular Advantage" in 2014, the consultancy firm Accenture defined five innovative business models with the main goal to create value by capitalising on the opportunities the circular economy brings along (Lacy & McNamara, 2014). The 5 business models are:

- **Product As A Service (PAAS):** Offer product access and retain ownership to internalise benefits of circular resource productivity.
- **Resource Recovery:** Recover useful resources/energy out of disposed products or by-products.
- **Product Life Extension:** Extend working lifecycle of products and components by repairing, upgrading and reselling.
- **Sharing Platforms:** Enable increased utilization rate of products by maing possible shared use/access/ownership.
- **Circular Supplies:** Provide renewable energy, bio based- or fully recyclable input material to replace single-lifecycle inputs.

An important note to make here is that organizations can apply hybrid forms of these business models, and they are not only applicable as single model.

ARUP & Ellen MacArthur Foundation (2020) defined a novel business model also called adaptable assets. They define adaptable assets as *"buildings that can accommodate more than one use during their lifetime through retrofit rather than demolition. The model operates through a new investment partnership; a long-term investor invests in the skin and structure, while a short-term investor rents this to adapt it for a specific use."* This business model separates the elements skin and structure, which are low in risk and therefore low in return yet long-term, from the services, space plan and stuff which are function-specific, high in risk, and higher in return yet have a short lifespan. For this a new stakeholder needs to be introduced in the supply chain, namely a long-term investor in an adaptable skin and structure (figure 15). By focusing specifically on structure and skin, the checklist for adaptability becomes narrower and more tangible to define. Key design requirements that need to be right straight away are for example floor-to-floor height, floor plate depth and core positions and entrances (ARUP & Ellen MacArthur Foundation (2020). Yet the choice to adapt or not is dependent on local market characteristics and location. Therefore, it can be stated that the adaptable assets model is better applicable to types of location, rather than types of buildings.

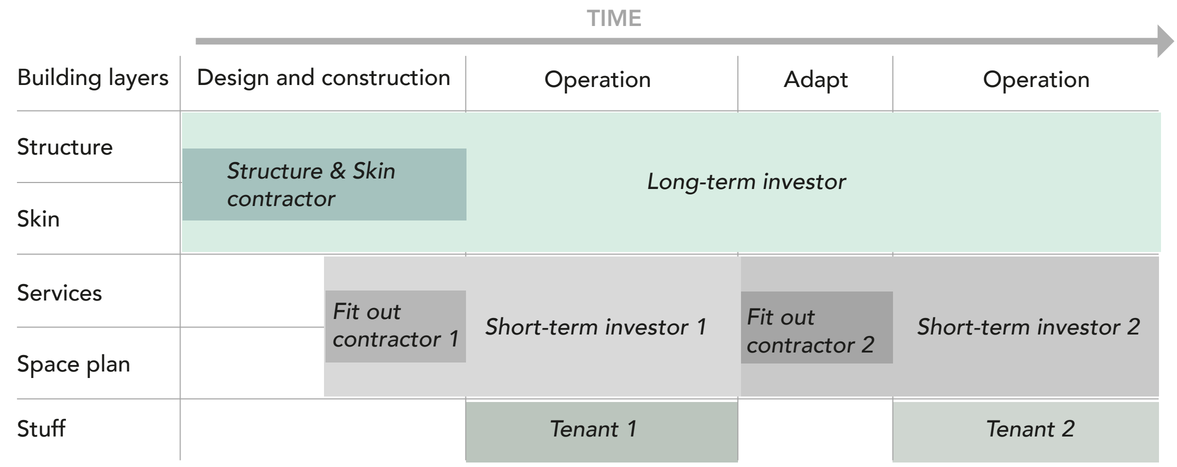


Figure 15. Schematic overview of adaptable assets by stage and layer (ARUP & Ellen MacArthur Foundation, 2020)

Another upcoming business model is the leasing of building components, the 'Materials As A Service' such as the skin or the stuff (Deloitte, 2019). Here the emphasis shifts from ownership to usage. And the owner has a benefit in keeping the lifespan of the product as long as possible, which means better care for demounting it and therefore less resources are needed. For the user the benefits lie in the fact that a part of the investment costs are now under the operational expenses.

There are several models on the spectrum from ownership to usage, which are distinguished below (FinanCE, 2016; Remmerswaal et al., 2017):

- Buy: The ownership moves from the producer and / or supplier to the consumer (buyer) through a one-time payment.
- Financial lease: During a lease / rental period, the consumer is allowed to use the product against a recurring payment and the consumer gets the product in ownership at the end of this period.
- Buy or lease with buy-back guarantee: Ownership shifts from the producer and / or supplier to the consumer "with the guarantee that the product will be bought back at disposal".
- Operational lease: The product remains the property of the producer and the consumer may use it against payment, which is possible in both one-off and periodic payment(s).
- Full service lease: An operational lease where services are also provided, such as for example maintenance.
- Pay-per-use: A full service lease where the ultimate costs for the use are variable and depend on the intensity and / or frequency of use and performance of the product.

An implication with building component leasing organisations is the lack of knowledge about development of value (Coalition Circular Accounting, 2020). With car leasing, the development of the value of cars is predictable as a result of a well-established second-hand market. Financiers of such an organisation can secure their funding by a collateral on the cars.

The cars can be sold and the value of risk has been covered. Since there is little historical data available about value of components, and there is no mature second-hand market yet for building components, this value development is currently still lacking, which obstructs the adoption of such business models at large hand.

A question that appears within the circular economy is whether it may be better to look at the value of separate layers instead of the value of the building as a whole. The valuation of a building is based on depreciation rates and cost increases. It therefore makes more sense to estimate the lifespan for each layer and calculate the depreciation rate separately, since it makes them more precise in reflecting the (residual) value of the layers. Therefore detailed depreciations are critical in a realistic (financial) reflection of the circular economy. Eventually this will also lead to better estimations in book value and residual values, and a more effective (re)use of value (Circle Economy, 2019).

2.3.4 Other circular approaches

Slaughter (2001) states that there are nowadays three general design approaches to increase building flexibility; the first one focuses on physically separating building systems and elements, which is already mentioned as the concept of shearing layers by Brand (1994). The second approach focuses on prefabrication of major system components. Modular buildings consisting out of factory-made elements that are reusable are less costly by being easily assembled and disassembled on-site. The third approach Slaughter mentions is to design with significant overcapacity so that changes can be accommodated without replacing or extending current capabilities. Sadafi et al. (2014) complemented the approaches of Slaughter with a literature review on 'design for adaptability' strategies. Table 6 shows the main strategies found and their sources.

Table 6. Design for Adaptability as mentioned by Sadafi et al. (2014)

Strategy	Suggested by
Increase regularity in building patterns	(Webster et al., 2005)
Increase simplicity in systems and materials	(Webster et al., 2005)
Design the core structure to be partitionable	(Macozoma, 2002)
Give specifications for connections, structural and installations	(Crowther, 2005; Macozoma, 2002)
Increase system predictability	(Keymer, 2000; Slaughter, 2001)
Improve flow through system layout	(Keymer, 2000; Slaughter, 2001)
Optimize use of interior space for optimal resource application	(Chini, 2002)

2.4 Financial models

From a financial perspective, a distinction can be made in the approach towards a real estate object. A building can be regarded as a means of production. Think of an organization that wants to develop a new office. The building serves as a means of production, here being it housing and shelter for example for equipment and machinery. On the other hand, a real estate object can be perceived as an asset. Real estate in this perspective is purely a commercial investment, just like stocks and bonds are. The physical features of the object do not directly matter; only indirectly can they influence the valuation of the object. It is for this aspect that investing in adaptability remains difficult, as the financial benefits are less visible than the physical benefits, while there is still a focus on the financial benefits.

A real estate object is often perceived as a trade-off between risk and return. Another word for return is yield, and a distinction can be made between direct and indirect yield. Direct yield is the direct return, which is mainly the rental income. Indirect yield/return is a return in capital, often the residual value of the real estate object after an X amount of time. The building's value, and thus the indirect return, also depends on the potential future rental income. The value can strongly decrease by the fact that it is vacant. This might be in contrast with its technical value, and here the mismatch between economic and technical lifespan of De Jonge (2000) comes in place again. The economic lifespan has ended, and therefore the market value of the property decreases, yet from a technical and environmental perspective, there remains a (re)use value in resources and elements.

2.4.1 Current methods

In the current linear economy, there are several methods in which a building's value is calculated. Usually the future rental income is taken as a benchmark. This paragraph will shortly elaborate on the static methods of the Gross Initial Yield (GIY) and Net Initial Yield (NIY), since these methods only take into account the first year of the investment. The so-called dynamic methods Net Present Value (NPV) and the Internal Rate of Return (IRR)) calculate over a defined period of future expenses and incomes. In addition, these methods take a residual value of the object into account, which is an important aspect of an adaptable building and the circular economy. Since this thesis focuses on adaptable tall buildings over time, the dynamic methods will be explained more in detail.

The GIY/NIY method is a simple calculation that divides either the gross or net rental income of the first year by the total investment. With the net income, the operational expenses are subtracted from the gross rental income. It is in fact a ratio of the income stream and the costs. A low initial yield means the income is relatively low compared to the costs, and therefore the risk is higher. Low initial yields will only be accepted in asset classes or locations where the overall risk is low (think of city centre objects, office with a long lease term, etc.). The GIY/NIY is a metric that is quite easily calculated, yet it does not include future developments in any form.

$$GIY = \frac{\text{Gross rental income}_{\text{year 1}}}{\text{Total investment}}$$

$$NIY = \frac{\text{Gross rental income}_{\text{year 1}} - \text{Operational expenses}_{\text{year 1}}}{\text{Total investment}}$$

That is why the Net Present Value (NPV) method gives better insights; all future incomes and expenses are discounted towards the current value of money. When all future incomes exceed the future expenses, the NPV will show a positive number and it shows that it can be an interesting investment. This method is particularly interesting since it includes all cash flows, meaning both operating and capital expenses. With an adaptable building the capital expenses are higher in the initial investment, but it is assumable that this is paid back by lower capital expenses when the building needs to be adapted to a second function. This "payback" over time should be somewhere visible in this method.

$$NPV = \sum_{t=1} \frac{Cash\ flow_t}{(1+r)^t} - Initial\ investment_{t=0}$$

Once it is known that the NPV is positive, investors would like to know what rate of return this object will generate. The internal rate of return (IRR) is the benchmark that is able to show this by setting the NPV to zero, and to solve it for an unknown discount rate. The rate that is produced here (often in excel by the goal-seek function) is the project's internal rate of return. The IRR is expressed as an percentage and allows for comparison among different real estate objects, which is useful in determining the most profitable object to invest in.

2.4.2 Lost value

As mentioned in the introduction, there is currently value unseen or lost with developing buildings. The report of ARUP & Ellen MacArthur Foundation (2020) identifies five main sources of lost value, based on roundtable discussions with investors, clients and policymakers. One source that came forward is the depreciation of materials. It means on the one hand that components or materials lose their value more quickly on paper than they actually do in practice, due to standard depreciation rates. There is a residual value in materials and elements that are currently depreciated to € 0. On the other hand lies the fact that buildings that are not designed for disassembly will have higher costs for recovering reusable materials. This results in smaller price differences between new and used materials, which cuts in the benefits for the developer.

Another source related to lifespan is premature demolition. Decisions to demolish are based on either the economic lifespan and opportunity cost, or the functional lifespan rather than the technical lifespan. Here the opportunity costs are most of the time demolishing and reconstruction costs that enable higher incomes in the long term due to the new functions that have become available.

At the end of a functional lifespan, there is always a residual value of elements and materials when their technical lifespan has not ended yet. This residual value can be used in re-use, recycling or upgrading of the material (Brink Groep, 2014). For this reason we have to start writing down which materials with which characteristics are in a building, which is called a materials passport. The materials passport contains information about volumes and qualities of materials, the demountability of these materials (into components) and their current location within a building (Deloitte, 2019). It also indicates a circular and financial value of these materials, even when a building is no longer in use. Currently only on material level this value is expressed. After all, at the product level, the materials have a higher value, because the material is processed using labour and energy into a usable product. In the Netherlands Madaster acts as an online register for materials in the built environment, and it is an independent public platform. Efforts by several institutions are being made for a certified method for determining this residual value of products / components.

The emergence of such a market for used materials and elements, together with increased standardisation and increasingly stricter environmental legislation can all positively influence the potential future values. In this way, value is better captured and it will decrease the pressure on the demand for 'new' resources.

2.5 Conclusion literature research

Adaptability has shown to be a concept with many definitions within the current literature and an important means for achieving a circular and sustainable building stock. It allows changes in function, and therefore extends the lifespan. In order to find an answer on the first sub-question *"What features have to be incorporated in order for a tall building to be adaptable?"*, the aspects that influence the feasibility of adaptability in tall buildings have been elaborated. The legal and technical aspects are mostly known and are summarized in table 7. The technical aspects are the ones that can be influenced and have a direct financial impact on the business case. Those have therefore been taken as starting point for an analysis of the cases.

Investing in real estate should no longer be seen in purely financial terms, but as a product subject to value development over time. This value development comprises of many influences, but one very important one is the residual value embedded in the elements. Residual value seems a key characteristic that will stimulate the re-use of an element instead of buying it new. The usage of material passports can provide better insight into this value. Besides, better and comprehensive standards and measurement tools to assess the circularity and durability of elements are needed, together with consensus on the definition of "sustainable". Only with this a circular economy can evolve and a shift towards long-term, circular real estate can be achieved. This will not only result in better adaptable tall buildings, but also in advancement and care for real estate with value for its users and environment.

Lifespan has shown to have different approaches in the current literature, with different layers and elements. Buildings should not be considered as being one object, but as the sum of different objects. Likewise, there is not one lifespan for the building, but many different lifespans for each different element. The most comprehensive approach which is also close to current practice is the six layers of Brand (1994), in which a building is broken down into Site, Structure, Skin, Services, Space plan and Stuff. Brand (1994) also defined ranges within which each layer's lifespan varies. Ranges are used since lifespans depend on the materials and elements used, as well as the level of maintenance executed over its life. Therefore, an answer to the second sub-question *"How can the lifespan be defined for a tall building in a circular way?"* cannot be fully answered by current literature. Literature only provides suggestions but a generic lifespan per layer applicable to all tall buildings seems unrealistic. In addition, little research has been done so far on this topic, which leads to a lack of scientifically proven evidence for lifespans per layer. In the empirical part, the lifespan will be further explored by looking into practice.

One important note with adaptable tall buildings is that the lifespan of the structure is the most critical and should therefore be maximized. A long-lasting, flexible structure can fulfil several functions and is the most durable in this way, since it does not require additional resources with transformations. In addition, the structure is the 'highest' layer in the hierarchy, meaning that this layer bears the other layers and it cannot be altered without being demolished.

The slow up-take of adaptability that is due to the 'circle of blame', as a report of RICS (2008) mentioned, explains the problem only partially. There is also a lack of communication about where each stakeholder stands in terms of sustainability and adaptability and what their interests and perceptions are, especially concerning risk. There remains a risk that an adaptable building will not be transformed in the future and additional investments will not be paid back. This can be regarded as a risk, although some might also say that with an adaptable tall building there is almost no risk at all. Communication, alignment and cooperation are critical here. The construction sector is a sector that absorbs innovation quite slow, yet there is substantial motivation and knowledge among different parties, only it lacks the needed communication to make progress and co-creation in adaptable real estate.

Table 7. Overview of features to increase adaptability

Legal	
	Land-use plan flexibility.
	Building Decree compliance.
Technical	
Structure	Generic and flexible layout: a central core or horizontal corridor.
	Free floors; Wide floor slabs loadbearing in two directions.
	Grid measurement of 1,8 m preferred.
	Small span core to facade; 5,4 m - 7,2 m - 9,0 m.
	Floor-to-floor height 3,6 m.
	Possible for horizontal floor extensions.
Skin	Design the facade as demountable and adaptable.
	Keep distinction between long-cyclical and short-cyclical facade.
Services	Locate services around or in the core.
	Never integrate services with structure.

III.

Case study

III. Case study

This chapter describes the approach towards the case study and complementary interviews. The cases have been elaborated by general information first, after which the findings from the interviews are discussed and lessons learnt have been retracted. This chapter ends with a cross-case comparison and a conclusion with the main findings of the cases.

3.1 Approach and selection

The chosen method for conducting this study is a multiple case study. Through in-depth and detailed data analysis a better understanding of complex processes can be obtained. By choosing for multiple cases, the differences and similarities between different cases can be studied (Gustafsson, 2017). In this way the author can clarify whether findings are valuable or not (Eisenhardt, 1991). The approach in this multiple case study has shown variations per case. In this thesis it is especially used as a tool for synthesizing information across time, in other words across different phases of a transformation process.

The cases have been chosen based on the following requirements deducted from the previous chapters.

- The demarcation of tall buildings requires a case to have a height of 70 m, as defined in paragraph 1.2.2.
- The building typology is either the central core tower type, or the horizontal corridor type.
- The building is located in a multifunctional area. Additionally inner city locations are preferred.
- The building should have an office function.
- The owner of the building should have a long-term focus.
- An important requirement is the retrieval of sufficient relevant documents concerning technical and financial data that should be obtainable. There is awareness about the fact that sensitive data is asked of parties that are in general reticent about sharing such information documents.

The case selection has been strongly demarcated by only using tall buildings. It is expected that by only selecting buildings higher than 70 m, increased comparability among the cases can be reached by creating similarity on certain characteristics. The demarcation has been specified by setting two typologies from the literature research that showed to be rather adaptable in itself by their dimensions and characteristics. Yet findings and conclusions may be applicable to more typologies than the ones used in this research, and to other functions and types of real estate as well.

There are four cases chosen for this study (figure 16). Over time, they are each in a different phase concerning the transformation. There are two cases that are already adapted from office function to housing, which are Park Hoog Oostduin in The Hague, and the Lee Towers in Rotterdam, also known as the former Marconitorens. As third case, the cylindrical building of De Nederlandsche Bank (DNB) located in Amsterdam has been chosen. This building is fully adaptable, and currently demounted to fulfil another function in the near future. Lastly, a case that is explored to be adapted in the future has been chosen, which will be the Faculty of Aerospace Engineering located on the TU Delft Campus.

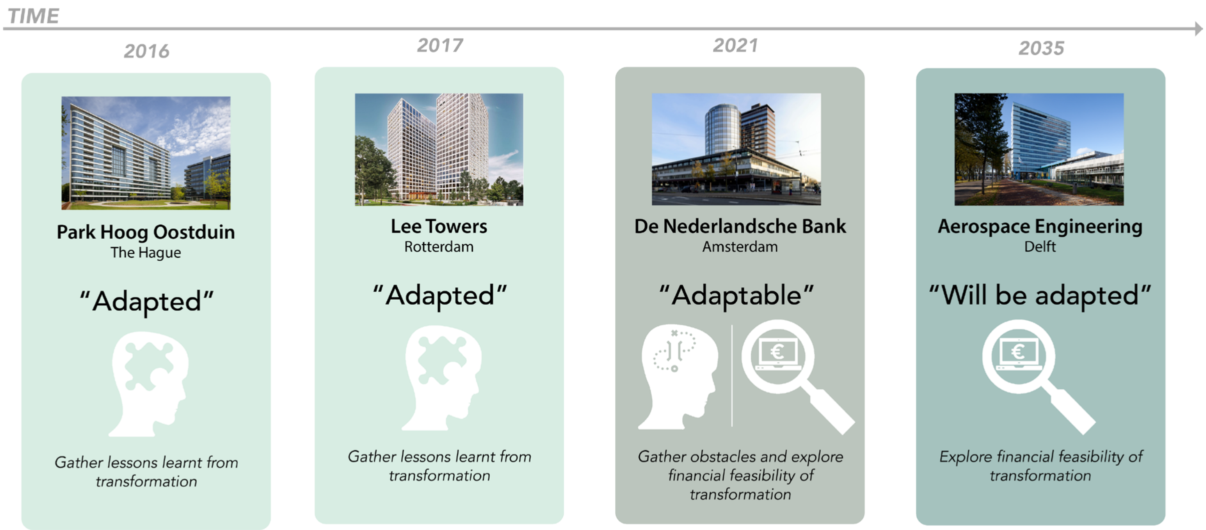


Figure 16. Overview of the three chosen cases (own illustration)

Figure 17 shows the contribution of each case in relation to the total empirical framework in an overview. The lessons learnt and the exploration both form main sources for the final set of adaptability conditions. Since different stakeholders are interviewed about different phases (before, during or after transformation) and on different topics, the interview protocols also differ in themes. Parallel to the interviews with involved stakeholders of the case study, additional interviews have been executed with professionals in the built environment regarding the long-term business case. The findings of these interviews are discussed in the next chapter.

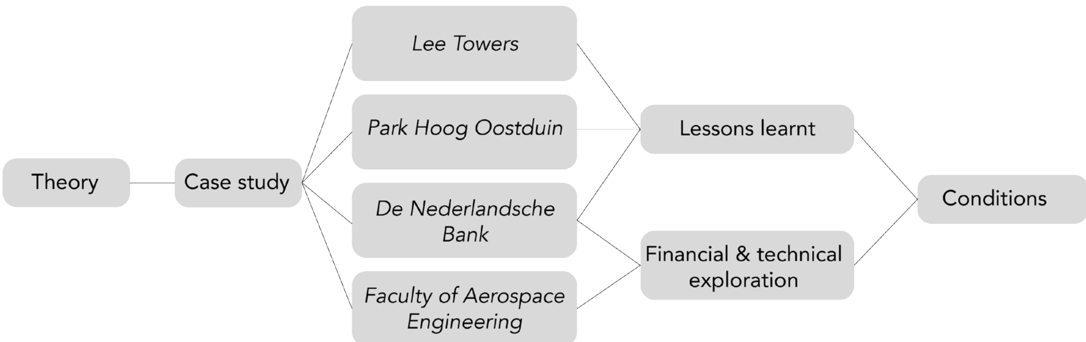


Figure 17. Empirical framework overview (own illustration).

Interview overview

The following stakeholders that are listed in table 8 have been interviewed for this research. In order to increase the validity and reliability of the interviews, an interview protocol has been sent to the interviewee in advance. In this way, the interviewee gets the opportunity to think about the information that is being asked, and it gives him or her the opportunity to find additional documentation if needed (Saunders et al., 2019). The interviewer has read the information about the case again before the interview commences. This can help during the interview in asking the right questions, but it can also increase your credibility and thus encourage the interviewee to go into more detail on the topic of conversation (Saunders et al., 2019).

Table 8. Overview of interviews (own illustration).

CASE	FUNCTION	
Lee Towers	Architect | Diederen Dirrix Architecten	Architect A
	Developer/owner | Bakkers Hommen Waerdevast	Developer A
Park Hoog Oostduin	Architect | Cepezed	Architect B
	Investor | Bouwinvest	Investor A
De Nederlandsche Bank	Developer | RE:BORN Real Estate	Developer B
	CEO | RE:BORN Real Estate	Developer C
Faculty of Aerospace Engineering	Sustainability Manager | TU Delft CRE	Asset manager A
Long-term Business Case	Senior Manager | Brink	Consultant A
	Partner | Alba Concepts	Consultant B
	Asset Manager | TU Delft CRE	Asset manager B

The background of each interviewee varies largely. Both public and private organizations have been interviewed, as well as educational employees. This has resulted in differences in quality of the interviews. Where one interview remained rather generic and reluctant in sharing information, the other provided very comprehensive answers. This leads to different types of results, which will be further discussed in paragraph 6.2 Discussion.

Resource types
With this variety of case approaches, different complementary sources have been used. Different dimensions of the same phenomenon are captured through multiple sources. The findings in the empirical part of this thesis are based on the following types of sources that are being distinguished:

- Documentation: Mostly consisting out of internal records, archival records, and publicly available online information.
- Interview: Semi-structured interviews guided by an interview protocol. Interviews are recorded under formal consent and transcribed.
- Personal communication: Informal conversations with involved stakeholders or professionals, of which a summary of findings has been conducted.
- Direct observation: Field visits, and observations of meetings.

The next paragraphs discuss the findings per case. First, an elaboration on the following topics has been given per case as background information:

- General project information.
- Ownership.
- Current status.
- Building image(s) and floorplan(s).
- Physical characteristics.

Secondly, the findings from the interviews are elaborated. Here, the main lessons learnt have been summarized at the end, and for the applicable cases a financial elaboration has been given. Lastly, a cross-case comparison has been executed, to expose the underlying differences. The chapter ends with a final conclusion.

3.2. Park Hoog Oostduin and Lee Towers

Two former office buildings that have already been transformed; Park Hoog Oostduin in The Hague and The Lee Towers in Rotterdam have been taken together in this thesis to explore the lessons learnt from transformations of such tall buildings. General information of each case have been provided below, after which the lessons learnt from the interviews have been taken together.

3.2.1 General information Park Hoog Oostduin

In the area of Benoordenhout, The Hague, a former Shell-office has been transformed into apartments in the higher segment. It was constructed in 1968 and designed by the son of well-known modernistic architect J.J.P. Oud. The building is located at the Oostduinlaan 75, which is right in-between the center of The Hague and Scheveningen. It counts 18 floors, covering 49.380 m^2 GFA, and with its height of 71 m it stands out of the green park surrounding it.

This building was part of a larger Shell-campus, and it consisted out of a higher part, a lower part and underground parking facilities (figure 19). The higher part and parking garage have been renovated and transformed, which is now called Hoge Duin, while the lower part has been demolished and built new (Lage Duin). For the case study and the analysis, only the Hoge Duin has been focused on. The property has been developed by Pinnacle Property Developers to be transformed into rental apartments and apartments and penthouses for sale, ranging from 70 to 200 m^2. The rental apartments have been adopted by the Bouwinvest Residential Fund. Bouwinvest is also the owner of the shared facilities in the plinth.

The former office had two horizontal corridors with offices along the facades, and stairs, elevators and shafts located at the heart. However, the former layout did not have enough depth for dwellings. Therefore, the corridor on the sea-side has been included with the apartments, and an extension of 3 m has been added to the former construction on the city-side. This extension consists of a steel "rack" with steel plate concrete floors, and it bears on the former structure, so no additional foundations were needed. Again, a standard grid of 1,8 m has been used in the structure. This meant that the apartment dimensions and layouts were still adaptable to market demands until quite far into the design phase.

The emergency staircases, which were located behind the limestone short facades, have been moved into the shafts at the heart. This allowed for additional and unique corner apartments. The longitudinal facades have been completely renovated according to current building standards. In addition, the building has a BREEAM-Excellent score and 80% of the materials released during the dismantling of the existing building have been reused in other projects.

Figure 18. Park Hoog Oostduin (Cepezed, n.d.)

Figure 19. Park Hoog Oostduin (Cepezed, n.d.)

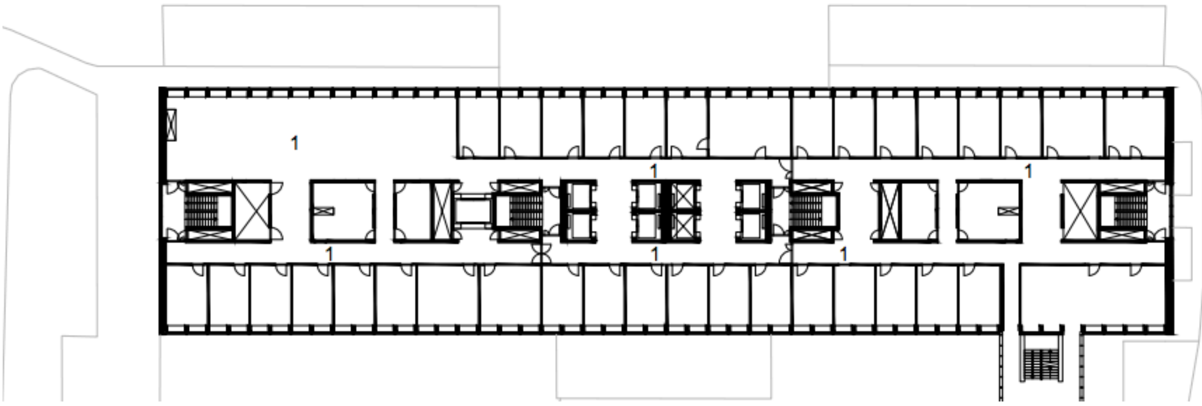


Figure 20. Floorplan before transformation (Cepezed, n.d.)

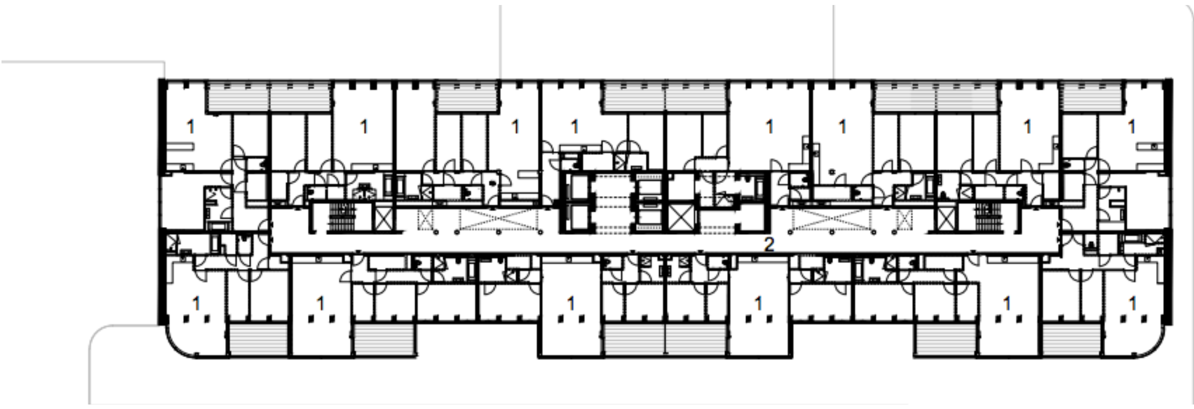


Figure 21. Floorplan after transformation (Cepezed, n.d.)

3.2.2 General information Lee Towers

The former Europoint towers have been built in 1975 by a design of Skidmore, Owings and Merrill (SOM). The three towers are located at the Galvanistraat 199, adjacent to the Marconiplein in Rotterdam, and therefore they are also called the Marconi Towers. The towers are located in the Merwe-Vierhaven area (also known as the M4H-area), which is transforming into a living and working area. Each building has a height of 93 m and counts 22 floors with a total of 35.400 m^2 GFA per tower.

Europoint II and III functioned as municipal offices until 2014, when they moved to De Rotterdam. The two office towers became vacant until 2016 when Citypads purchased Europoint III, and Bakkers Hommen Waerdevast acquired Europoint II in 2017. Together they transformed the offices into 883 mid-rent apartments with layouts starting from 38 m² to 127 m². Until today the towers are still owned by the developers, that keep their buildings in own investment portfolios. The property management and rental has been outsourced to Holland2Stay, and Europoint I has remained an office tower, nowadays called the Rotterdam Science Tower.

The dimensions of each rectangular tower are 33 by 47 m, with a standard grid of 1,8 m. After every six floors, the facades and structure are six centimeters wider. This architectural correction makes the towers look perfectly straight. The structure consists of load-bearing concrete columns in the facade complemented by a concrete core for eight elevators, two stairs, toilet groups and technical areas. The depth of the apartments from the facade is 7,2 m or 10,8 m. The facades consist of a grid of light-coloured travertine (natural stone) alternated by square windows with dark reflective glass, which gives the buildings a modernistic look.

Figure 22. The Lee Towers (Diederen Dirrix Architecten[1], n.d.)

[1] Internal information of Diederen Dirrix Architecten.

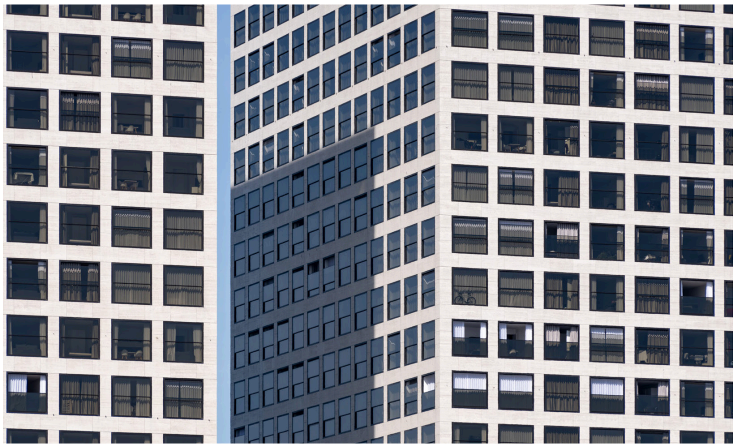
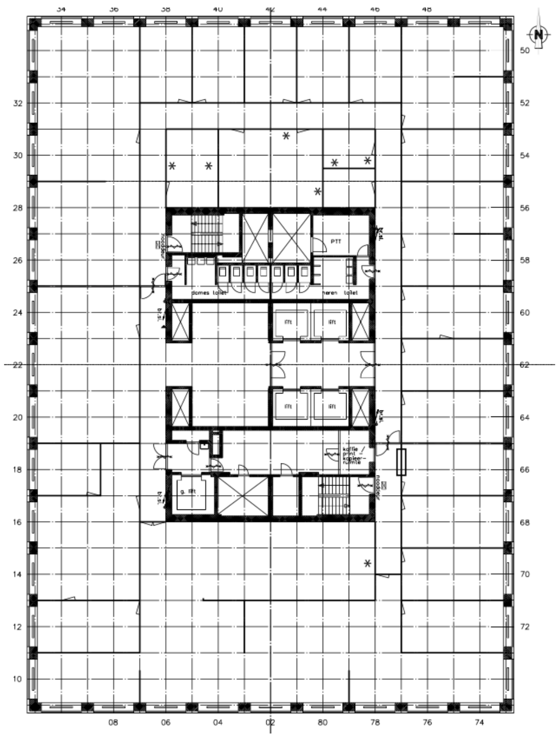


Figure 23. Facade of The Lee Towers (Diederen Dirrix Architecten[1], n.d.)



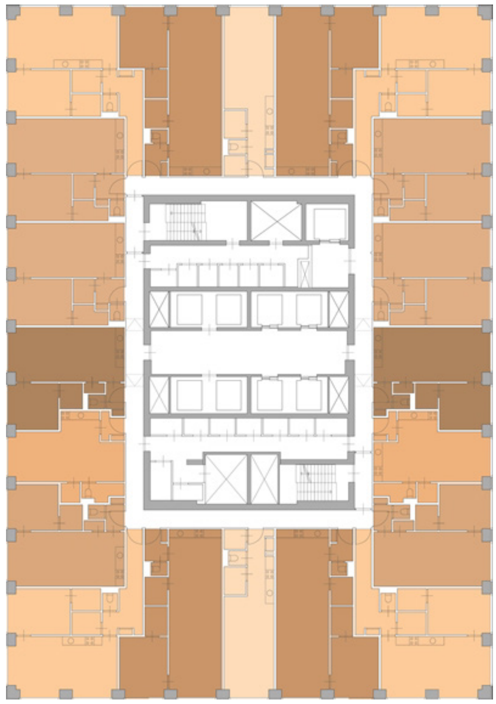


Figure 24 and 25. Floorplans before and after transformation (Maria Haag Architectuur, 2013; Diederen Dirrix Architecten[1], n.d.)

3.2.3 Interviews

The Lee Towers and Park Hoog Oostduin have shown to be two successful transformation projects. Since these two cases have already been transformed, the lessons learnt are the most important type of information to gather by the use of semi-structured interviews. With each of these cases an interview with the developer/owner and the architect have been executed as main stakeholders in the process. The interviews have been guided by the following themes:

- **General:** an introduction to their role and main responsibilities within the case study project, as well as their experience with other transformations.
- **Transformation in general:** their perception towards transformation, its benefits and drawbacks, as well as its lifespan.
- **Transformation project specific:** more specific questions about the flexibility of the building per layer, how it is dealt with and to what extent the transformation has improved the adaptability.
- **Process:** How the process has influenced the transformation, with choices made and the degree of freedom in making choices.

Process
The architect of the Lee Towers remarked a shift in the design process. More efforts lie in the beginning phases of the process, *"because actually a transformation often commences with a lot of technical research. You start with analyzing what the determining and constraining parts are of the building"* (Architect A). Where in a new development the technical research and elaborations come with the final design phase, a transformation starts with an existing form for which technical research is needed upfront before deciding what interventions are wanted and needed. The amount of knowledge and expertise is rather high immediately commencing a transformation, which led to the fact that a contractor, advisors and suppliers have been involved rather early. Architect A mentioned that this was not only applicable to the Lee Towers, but to all of their transformations.

Business case
With both cases, the focus from the clients was still on the business case rather than on transforming for reuse or sustainability. In the financial model of Investor A, the building is also approached as a new real estate object; it does not differ from traditional even though it concerns a transformation. Investor A of Park Hoog Oostduin mentioned that they do not take residual values or demountability into account. Their main reason is that all processes and models have not been approached in this way, and it is still in its infancy. There are tools used by this organization in which a lower yield is justified if the building meets certain other conditions. A building that scores very low in terms of sustainability must have a higher yield than a very sustainable building. In some projects it is explored what circularity could mean, but this remains explorative. Also, as Investor A mentioned, *"we have to deal with the fact that we invest for pension funds, and how do we convince valuers and other stakeholders to take such things into account."* He also mentioned that legislation and a solid basis or foundation for the valuations are needed for them to make a step towards the long-term business case.

The organization of Investor A still reasons in a traditional way that a building is being sold in its totality. Their portfolio is being valued every year and that value is being recorded in the balance sheets and other accountings. If a disposition is being decided, that appraisal value must be the minimal price. To the question about a business case divided in different building layers with residual values, Investor A answered that he did not expect this to be implemented on a short term within his organization. *"Residual value is important after you have depreciated the building"*. This exemplifies the linear way of thinking. In a circular economy, residual value should be calculated with upfront, and not afterwards after a certain estimated lifespan, being regarded as a gift.

Structure
The Lee Towers has a very generic tower design of SOM that followed the 3,6 m or 1,8 m grid in every layer, which was a great benefit. It has a loadbearing skin with loadbearing core, so basically a tube in a tube concept, as Architect A mentioned. This makes the floors flexible to arrange. The floor-to-floor height is high enough that in relation to services, you never have to encounter problems with altering them, and the height adds quality to the apartments. As for Park Hoog Oostduin, the free height of the floors was also good, as well as the high-quality concrete of the structure. The free floors along the facades were a great benefit that together with the form led to apartments oriented along the facade instead of perpendicular to the facade. The structure and main layout have remained the same, so if another function is desired in the future, a similar intervention as this transformation would be needed.

The only drawback that came forward with both the Lee Towers and Park Hoog Oostduin was the design of the core that was less flexible. With the Lee Towers, the core was relatively large, due to ventilation systems with large shafts that were included, but also facilities such as repro rooms were located in the (loadbearing) core. Especially the function-specific facilities are better to exclude from the core and incorporate in the space plan of the free floors. With this transformation, a solution has been found in allocating the storages of the apartments partly in the core, and partly in the basement.

Park Hoog Oostduin has its entire middle zone (between the two former corridors) consisting out of several cores. There were multiple staircases and shafts which could have been designed more efficiently with less replications. So both cases show some initially made design choices that now have led to more interventions, and therefore a lower degree of adaptability. Again a solution has been found by adding the steel rack and creating one central corridor instead of two. Still, the main lesson from both cases is to keep the core flexible and generic, by including only the essentials and excluding function-specific facilities from the core.

Skin

For the Lee Towers, the skin formed the largest challenge. The unity in the towers had to be preserved, but at the same time the clients wanted the skin to better facilitate housing. In addition, the facade was stacked, composed of travertine natural stone and in a technical good state. So from a technical point of view it was unpleasant to not reuse the skin (expensive in labor and material), but also from an environmental point of view; it would be a shame to discard it, and destruction of a natural and still decent resource. A solution was found, yet in the future adaptability of a skin could be enhanced by not designing stacked facades, but a facade that is demountable per element, and in which short- and long-cyclical elements are distinguished.

Architect A elaborated further: *"A facade supplier has been involved immediately, after which we came to the solution rather fast. The whole infill of the window frame would be removed, and the existing window frame would be reused as framework for a new window. This resulted in somewhat thicker window frames, but it provided the option to insulate the building extra on the inside"*. Again, early involvement of a third party led to the solution, and it could be combined with a small intervention that would result in major benefits, namely the additional insulation.

In the case of Park Hoog Oostduin, only the loadbearing column grid on which the facade was attached remained during the transformation. The whole skin consisting of separate window frames and enameled glass had been demounted and replaced by a new facade, also demountable per element again. The demountability has shown to be the greatest benefit. Architect B also mentioned that sometimes different appearances are needed in different locations and demountable elements should be capable to change its appearance. Therefore it is important for the parts most subjectable to change to need little resources, and that part that you always need, insulated facade panels for example, that you can take that part to another location.

Services and Spaceplan

A loadbearing structure allows for the spaceplan to be altered easily, since no loadbearing walls are needed. But with both the Lee Towers and Park Hoog Oostduin, no other future functions have been taken into consideration. Both cases have been transformed from office to residential with the assumption that it will always remain residential, because the demand for housing is assumed to remain high. For this reason, both Architects A and B emphasized that adaptability to another function has not been a focus, but rather the flexibility within the same function was relevant. This has been guaranteed by the non-loadbearing, demountable separation walls, and a path around the core/corridor above which all installations are located and can be altered. In this way the services always remain accessible and adjustable. Also Investor A confirmed the focus on flexibility with residential buildings, and mentioned that with other funds such as the Health Care Fund, adaptability becomes more important, where they call it 'alternative usability'.

General benefits

The benefit that has been mentioned most often during the interviews was the uniqueness of living in a building that was not initially designed for housing but has been transformed into it, and the presents that come along with it. As Architect A mentioned it: *"The difficulties or anomalies that you encounter are often also the presents. Where an existing building does not fit with a standard housing product, it provides solutions in making it a unique housing product."* The Architect of the Lee Towers calls it 'product incompatibility'. Architect B of Park Hoog Oostduin mentioned the same benefit, namely *"a larger housing quality, and a different housing quality"* that you would not and could not develop in the same way. Still, in order to transform a building, the structure must be flexible and suitable for the allocated function, which makes it the most critical layer.

A benefit of transformations, but also with Park Hoog Oostduin specifically, was that *"such a large building volume that was located in a park was something you would never accomplish anymore nowadays. Especially not in such an expensive living area"*. So the combination of such a tall building volume on such a location will rarely occur again with new construction, and that is where existing buildings can become very valuable. This was also the main reason for Investor A to invest in this transformation. In the case of Park Hoog Oostduin, the existing volume also allowed for slightly increasing the building's dimensions. Because of the added value of the undergone process, meaning building forward on an existing building, you can have additional benefits compared to new construction, especially on inner-city locations. Another benefit that Architect B stipulated was that besides the saving in resources such as labor and materials, there is also a saving in nuisance to the neighborhood by building further on existing structures that is often forgotten.

Architect A mentioned the relevance of architecture and uniqueness in the willingness to keep buildings occupied and to not demolish them. Tall buildings specifically often have a distinct and architectural character that makes them valuable for its environment. In addition, the large height and high level of quality are also influencing factors on the decision to demolish or not.

Lessons learnt

- More efforts are needed in the beginning of the design process with substantial technical research and analysis of the existing building, in order to decide what interventions are wanted and needed.
- The structure is the most critical layer and must be flexible and generic.
- Keep the core flexible and generic, by including only the essentials and excluding function-specific facilities from the core.
- Make a distinction in the skin between parts that are most subjectable to change and design it with as little resources as possible, and parts that are least subjectable to change to be demountable to take to other locations.
- For maximum adaptability, try to avoid designing stacked facades, but rather design it as demountable per element
- With recent transformations to residential, the focus on adaptability to another function seems less relevant, but flexibility remains important. Focus lies more on flexibility of space plan and services than adaptability of higher layers.
- The benefits of an existing volume on a specific location can be the most valuable factor of a transformation, because some volumes can never be accomplished anymore on such locations nowadays. Continuing on an existing structure also holds benefits related to the process and nuisance.

Other findings that have been mentioned during the interviews and are worthy to mention are mentioned below:

- Architect A mentioned the following: *"We should maintain buildings better, because if you take the idea of adaptability into account in the design phase already, the trigger will be bigger to maintain better and to transform eventually."* This could partly solve the problem with vacant buildings that are technically in poor state, which makes them less suitable for transformations and financially more attractive to demolish.

- There is something to say about over-dimensioning in some parts of the building. Example: With Park Hoog Oostduin, a whole parking deck could be added because the columns could endure a high load. Over-dimensioning of some parts can be part of a strategy for increased adaptability.

- According to Architect B, every transformation from office to residential comes down to three general challenges:
  1. Get the routing right, so how to access the dwelling (also mentioned by Architect A).
  2. Get the acoustics right.
  3. Create a good outer space.

- Architect B: *"Do not try to work on everything. You have to maximally maintain what is good, and only work on that what is needed to make it better and allow a new function. And put all your efforts into that. Accept that the building is what it is and use its characteristics to continue from that."*

- Architect B: *"Chances are higher that a building remains in the same location but gets another function than the chance of demounting a whole building to build it up again at another location"*. So demountability should be ensured for all layers except for the structure. The structure will remain and needs to be flexible, while all other layers need to be adaptable by being demountable.

- Architect B mentioned that their use of the shearing layers by Brand (1994) is to have more grip on the different elements. The focus on demountability and prefabrication is in their DNA, also because of the following benefits:
  - Assembling on-site, which leads to a shorter construction time.
  - Higher efficiency and less agitated workers on-site
  - Less waste, since most actions are being done in the factory, and there they can close their own loop very well. To them, their waste is also again a resource, because they work in the same materials.
  - Demountability allows to better steer on replacements and lifespan.

3.3 De Nederlandsche Bank

3.3.1 General information

Since 1968 the headquarter of De Nederlandsche Bank (DNB) is located at Westeinde 1 in the centre of Amsterdam. In 1991 a cylindrical building designed by Jelle Abma was added. Both towers became well-known as it resembled a stack of coins placed next to a stack of banknotes. The cylindrical tower is 66 m high and counts 14 floors and a smaller crown. In total the tower's GFA is 7993 m^2 (582 m^2 per "coin").

Since 2020, DNB HQ will be renovated by the architectural firm Mecanoo. In this renovation, the cylindrical addition will be removed, returning to its original form again. The cylindrical building has been acquired by RE:BORN to disassemble and to build up elsewhere in Amsterdam in a renewed form. Yet for this case study, the building is assumed to remain located on the current location (figure 26) as still a tower that will be transformed to dwellings, but with the potential of being demountable.

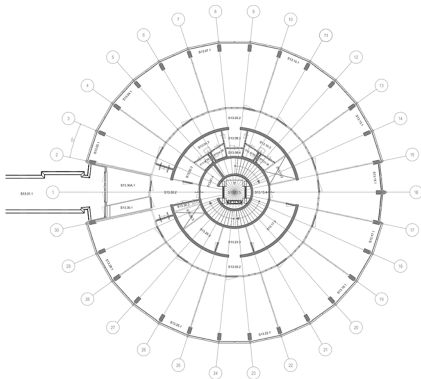


Figure 26 and 27. Photo and floorplan of DNB tower (RE:BORN, internal communication).

The tower has a central core with a diameter of 6,5 m with emergency staircases going around a shaft with elevator. A corridor zone with a width of 2,4 m embraces this core. From the corridor till the facade the radius is 7,5 m, which gives the building a diameter of 26,3 m. The structure comprises of concrete floor slabs, columns, walls and stairs. The facade elements will be refurbished to comply with the Building Decree again, and can aesthetically be upgraded if desired.

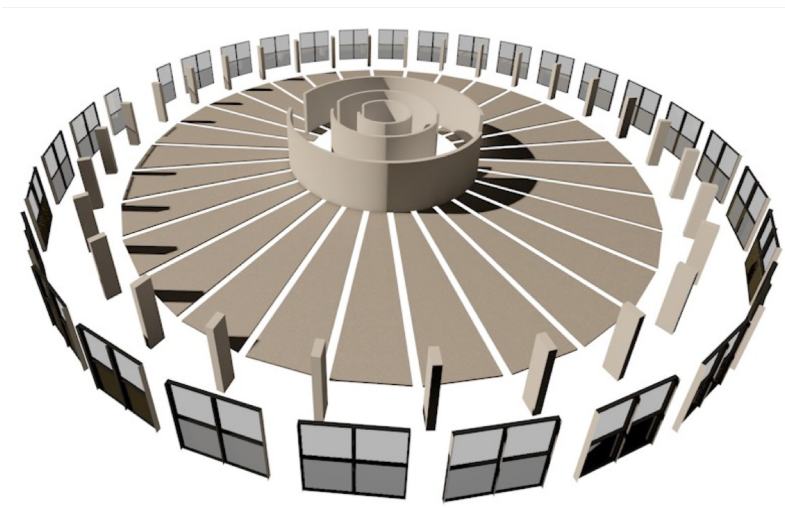


Figure 28. Exploded view of the structure per floor (RE:BORN, internal communication).

3.3.2 Interviews

The main aim with the case study of DNB is to gather the lessons learnt so far in the process, and to make an exploration into the financial added value of adaptability. Since there is no architect on board yet, only the perspective of the developer has been interviewed. The findings and lessons learnt are discussed below.

Lifespan

The lifespan differs per layer, and the developer also works with the layers of Brand (1994). Yet it was mentioned that lifespan per layer is also influenced by function. Space plans of offices may alter more often than for example for schools. This is closely related to the usage which differs per function. It can also be noticed that the fluctuations become smaller the higher on the layers of Brand (1994), and the long-cyclical layers are actually quite similar for all, if designed right.

Site

A risk that comes with remounting this building is to find a proper location for it in time, with permission of the municipality and the neighborhood. Of course with an existing building, aesthetical objections may occur. If this process takes longer, it can lead to immense storage costs. If agreements upfront about location would have been made, the risk would be lower.

Structure

As mentioned before, the usage of prefabricated elements is a major benefit in the adaptability of the building. However, the elements have been connected by wet connections, specifically by pouring concrete. For disassembly more efforts are needed by sawing the concrete connections, or by chopping it open. The developer is currently investigating which types of dry or wet connections can be best used for its second assembly. Also, the columns have a height of 2 floors, and have been applied alternately. This decreases the adaptability, since the height can only be a multiplication of 2, or further adaptation is needed.

Another downside concerning the structure was that the shaft for the elevator could not facilitate a larger elevator, which may be needed for other functions such as care. Again, the dimensions of the core are very critical for adaptability and transformations.

Skin

The skin consists of large panels, and with minimal interventions, the skin can be technically compliant to current thermal performance standards. Yet the main risk lies in the aesthetic desires; this mainly determines the additional investment. Another challenge lies in creating horizontal extensions such as balconies. According to the developer, the initial investment would not be much larger by incorporating the ability to extend with balconies in the future. Still it is possible to create openings in the panels. So the skin is the largest challenge of this redevelopment, but the developer stipulated that skins in general are difficult to reuse. Still it is the ambition to do so, and different variants are explored for it. As the ability for horizontal floor extensions has already been mentioned in the literature, this will not be considered a lesson learnt in this research.

Business case

A business case of such a redevelopment with reused elements needs a different approach. The developer has split the business case by the different layers of Brand (1994). Traditionally, the building costs would mainly consist of materials and labor. In this case, for the structure and skin layers, the material costs are € 0 but this saving is actually replaced by the costs of demounting, transporting and the storage of the elements. Also cost items for labor and refurbishment have been included. Based on the traditional business case, it is calculated backwards what the refurbishment may cost to keep it less expensive than new construction.

The business case has first been calculated as traditional, leading to a building costs total. This total has been set as requirement that reuse must be less expensive than new construction in the traditional method. The building costs savings are also a compensation for a higher risk-profit margin, because especially with such reuse, problems can be encountered which need additional investment. In other words, the fact that reuse needs to save costs is because other cost items such as refurbishment, transport and storage of the elements can be higher.

"Even in an unequal competition between the linear versus the circular economy, where it is obliged to pay taxes on the existing materials from the DNB building, the costs are no more than new construction. But you get more quality, so higher rooms and a circular building form, which leads to more surface for its price since with circular forms the inefficiency is higher. For this inefficiency you get larger rooms." This is mostly achieved by the early involvement of partners, which resulted in good arrangements in disassembly, transport, storage and refurbishment. Yet this leads to high costs and high risks in the beginning of the process that eventually flatten, while in a traditional development, the costs and risks slightly increase during the process.

The value of its adaptability and flexibility lies in lower interest rates because of its lower vacancy risk profile, lower transformation costs, and because it is a sustainable development there are lower operational costs. The adaptability has been ensured by elaborating different functions in structure, skin and spaceplan. As already mentioned, the only obstacle might be the core.

With such a project of reusing elements on such a large scale, a risk has been taken by purchasing elements on reuse value, not on material level, without having the certainty that the elements will be reused on element level or whether they eventually end up being recycled. In that way the investment will be lost.

Residual value
The developer had made several calculations relating to the value of the building. It was calculated what the value is as office. There was also an appraisal of the elements, in other words; what would the building costs be if it would be built with 'virgin' elements. Another calculation has been made by purely looking on material level. Eventually, a value has been estimated based on its reuse value.

Maintaining that value is another risk with interventions such as disassembly, transport and refurbishment. It is important to monitor the performance of elements to ascertain that the estimated state of the element is eventually being delivered. For this, several checks and balances are incorporated along the process, which is called Service Level Agreements. Note that it can be of importance for both owners and (service) suppliers.

General benefits
One of the benefits also mentioned by Developer C is that you can build further on what is already good. *"You already have the contours. Also, the procedures are less difficult, because the neighborhood is already accustomed to the building or wants to see the building slightly different. So it is easier to start the conversation with the neighborhood. And often when you buy an existing building, there is a current tenant in it that could partly cover the financing costs."* Another benefit he mentioned was the fact that other regulations apply to renovation compared to new construction.

Ownership
The intention is to build and to retain the building in own portfolio, because it allows to have more influence on the projects than when selling it to another investor. This developer implements a long-term focus with the intention to maintain it, if possible. If not, the building will be sold, but the choices made for the long-term are already implemented and the future owner is able to experience the benefits of it. For safeguarding their influence and ownership, this developer has two funds: a Debt fund, in which they are the legal and financial owner, and an Equity fund, which means another party purchases the building and the developer manages it. Here the developer is legal owner, but not financially, but it still allows for own decision-making in the long-term perspective on principles such as sustainability, flexibility and emotional value.

Lessons learnt

- Besides the difference in lifespan per layers, there is also a difference in lifespan due to its function and the degree of usage that comes with it. The differences among functions are larger in the short-cyclical layers (services, spaceplan and stuff), while the differences are smaller in the long-cyclical layers (structure and skin).
- Much risk is taken since the disassembly has already commenced while there is no agreement on a location where it will be remounted. Earlier agreements about the location would have led to lower risks.
- In future designs with prefab elements, make sure the elements can be disassembled and assembled per floor for optimal flexibility.
- The dimensions of elevator shafts are critical and can obstruct future functions where large elevators are needed.
- A requirement for adaptability is that it may not cost more than new construction, but this is mainly because compensation is needed on other cost items such as storage and refurbishment. Also, because it takes place in a linear system with regulations and taxes conform the linear economy that disincentivizes the circular principles. In addition, an existing structure can lead to higher quality that would not have been designed in new construction.
- Early involvement of different expertises is very important, leading to substantial research and analysis of the building upfront, and good arrangements later in the process. *"You cannot bring in enough analyses and experts on day 1".*
- Incorporate several checks and balances along the process by establishing Service Level Agreements with other parties.
- Keep everything that is already good, and try to keep all new elements as adaptable as possible by dry connections and according to the distinguished layers.

3.3.3 Financial exploration

The second part of this case is to explore the adaptability the building possesses from a financial perspective. A concept version has been drafted and discussed with internal stakeholders, after which several sessions have followed to improve the document. The financial exploration has been validated in a separate session by internal stakeholders from the graduation organization.

For this exploration, a comparison will be made between two scenarios to exemplify the difference, namely a traditional and a circular approach. In both scenarios, different costs and benefits have been set out over time which will be elaborated below by substantive argumentation and validation where necessary. In the end, this part aims to validate that there is an added value of adaptability in the long-term, by using this case as first exploration. Appendix C shows the elaborate overview from Excel. Note that with all amounts VAT is excluded.

1990:

De Nederlandsche Bank needs more office space and decides to develop an additional tower. Because of the limited space that is available for construction site and for the building to land, the solution was to make use of prefabricated elements that are easily assembled on site. This is believed to be the main reason for its demountability that is currently found beneficial.

If the building would have been built traditionally, it would lead to building costs of € 1500 / m^2 (validated by RE:BORN). In the circular scenario, a surplus of € 75 / m^2 has been taken, which leads to building costs of € 1575 / m^2. This difference lies mainly in the structure; in the traditional scenario, a less flexible structure with loadbearing inner walls have been taken as principle, while in a circular design, free floors is a criterion for flexibility which means the structure consists of loadbearing columns. The building costs for skin, services and spaceplan are assumed to be similar in both scenarios. This leads to a difference in capital expenses of € 614.250.

Construction	Price / m2	Total
Traditional		
Building costs	€ 1.500	€ 12.285.000
Structure: *linear load (structure and spaceplan partly combined), wet connections used leads to lower costs, but only downcycling is applicable for the future.* ***Skin:*** *Curtain wall* ***Services:*** *Central heating and cooling* ***Space plan:*** *Partly loadbearing, partly metalstud walls.*		
Circular		
Building costs	€1.575	€ 12.899.250
Structure: *Point load, column grid. Design for dissassembly leads to higher costs, but there is also a residual value potential (both with transformation and demounting and remounting).* ***Skin:*** *Curtain wall* ***Services:*** *Central heating and cooling* ***Space plan:*** *Metalstud walls.*		
Difference		€ 614.250

2021:
After 30 years, when De Nederlandsche Bank does not need the additional space anymore, there are two options:

- **Traditional:** The cylindrical building will be demolished. Demolition costs are € 680.000 (validated by RE:BORN).
- **Circular:** The cylindrical building will be harvested for reuse. Harvesting costs are € 1.800.000 in total (including the demounting, transportation and storage) (validated by offer external party)

Difference in costs is € 1.120.000. In other words, it requires an additional investment for harvesting, but note that a residual value of the elements is incorporated in this, and this residual value is preserved until next usage.

Removal	Price / m2	Total
Traditional Demolition costs	€ 83	€ 680.000
Circular Harvesting costs	€ 220	€ 1.120.000
Difference		€ 614.250

2022:
Depending on which scenario chosen, new construction has been initiated on a different location. This leads to the following two paths:

- **Traditional:** Reconstruction of a new building with 'virgin' materials will be executed. Building costs are € 6.175.260 for structure and skin.
- **Circular:** Reconstruction of a new building with demountable elements (where possible) and 'virgin' materials will be executed. Building costs are € 4.111.380 for structure and skin.

The table on the next page shows an overview of the different building costs per layer. It illustrates that especially in the layers structure and skin materials are reused. For that reason, the cost component of material is € 0 for the Circular scenario. Still, other cost components are needed with the Circular scenario such as refurbishment The difference between both scenarios is € 2.063.880, assuming that the layers of services and spaceplan are similar in both scenarios.

Reconstruction	Price / m2	Total
Traditional		
Building costs		
Structure	€ 439	€ 3.595.410
Material	*€ 272*	
Labour	*€ 71*	
Foundation	*€ 96*	
Skin	€ 315	€ 2.579.850
Material	*€ 236*	
Labour	*€ 79*	
Total		€ 6.175.260
Circular		
Building costs		
Structure	€ 255	€ 2.088.450
Material	*€ -*	
Labour	*€ 71*	
Refurbishment	*€ 184*	
Skin	€ 247	€ 2.022.930
Material	*€ -*	
Labour	*€ 79*	
Refurbishment	*€118*	
Upgrade to BENG	*€50*	
Total		€ 4.111.380
Difference		€ 2.063.880

2052:
After its functional lifespan, for which 30 years has been taken again in this exploration, the building becomes vacant and has the following difference in scenarios:

- **Traditional:** The building has been depreciated for its total building costs over 30 years, which leads to a residual value of € 0.
- **Circular:** A residual value has been taken into account for the different building layers. The approach for calculating the residual value is based on the minimum value, which is the recycle value for skin, services and spaceplan. The structure has been approached by indexing the building costs of 2022 to 2052, since the structure has the same technical quality and needs no refurbishments from a technical perspective, which indicates it maintains its value very well.

Residual value
Traditionally, a building is depreciated by dividing the initial investment (building costs) over its lifespan, which leads to a residual value of € 0 when its lifespan has ended. In a circular economy, materials and products are always reimplemented into the chain instead of being retracted or considered as waste. For this reason, an attempt has been done on estimating a residual value. This exploration only considers the structure and skin as long-cyclical layers that will have a residual value; the space plan and stuff have a short lifespan, and have been replaced several times by 2052. Therefore it seems very speculative to estimate a residual value. As for the services, it is assumed that in 2052, two technical lifespans of 15 years have been fulfilled and the service is at the end of its second lifespan, meaning no residual value is there to take into account.

The table below shows an overview of the estimation. The residual value of structure and skin has been calculated at € 6.84 million. Since the structure will hardly decrease in quality and can still be reused 1-on-1 after 30 years, the building costs of 2021 have been indexed to 2052. For the skin, the panels have been decomposed into the aluminum skin panels, bronze profiles and glazing in kg of materials. The material price per kg has been indexed to 2052 as estimation of the recycle value on material level after 30 years. It illustrates that the reuse value on material level is significantly lower than reuse value on element level.

Residual value	Weight in kg	Price / kg (2021)	Price / kg (2052)	Total
Structure (indexed)				€ 6.642.839
Skin				
Aluminum skin panels	14.400	€ 2,03	€ 3,76	€ 54.144
Bronze profile	14.400	€ 4,25	€ 7,85	€ 113.040
Glass elements	110.000	€ 0,13	€ 0,24	€ 26.400
Total				€ 6.836.423

CO2 and environmental costs

MPG stands for Milieu Prestatie Gebouw (Environmental Performance Building) and it translates environmental impact including CO_2, nitrogen and acidification, into environmental costs in euros per m^2 GFA per year. The MPG calculation is already part of national legislation, and it will also become the sector-wide basis for a uniform assessment method for circularity.

A third party has executed this calculation for DNB which has shown an environmental cost saving of € 144.507 by reuse of the structure and skin elements . This leads to an MPG of 0,35, meaning € 0,35 per m^2 per year has been saved by harvesting DNB, as part of the circular scenario. Within this calculation, an amount of CO_2 of 1.338.676 kg eq. is considered as embedded in the structure and skin elements that are reused, and therefore this amount is not emitted for new production.

MPG = €144.507 / 8.190 m^2 GFA / 50 years = 0,35

As for the traditional scenario, the above mentioned environmental costs and CO_2 emission are counted as costs for new structure and skin elements. The layers of services and spaceplan and stuff, which are normally also included in the MPG, have now been estimated based on ratio outcomes in calculations of reference projects of the same developer. On July 1, 2021, the MPG for dwellings will be strictened from 1,0 to 0,8 as maximum (RVO, n.d.). Based on the new requirement and the shares of the different layers, an estimation has been derived, which is shown in the table below. Yet for the traditional scenario, the 0,35 has to be taken, which means if constructed in the same form with all 'virgin' materials, the MPG requirement would have been surpassed.

	Average share of total MPG (Based on reference projects)	Maximum allowed based on the 0.8 requirement	MPG per layer Traditional	MPG per layer Circular
Structure and skin	31%	0,25	0,35[a]	0
Services	49%	0,39	0,39	0,39
Spaceplan and stuff	20%	0,16	0,16	0,16
Total	100%	0,8	0,9	0,55

[a] Internal document of RE:BORN, not publicly available.

This approximation is based on assumptions and reference projects outcomes. For the validity of the whole financial exploration, only the validated numbers of structure and skin will be taken into account. This means that in the traditional scenario, the environmental costs of € 144.507 has to be included in the total investment, whereas in the circular scenario, this amount has been saved by reusing structure and skin elements.

Conclusion

Table 9 and figure 29 show an overview of all investments over time. From this, the following can be concluded:

- A higher investment at t=0 (1990 in this case) can lead to a structure that is adaptable in its current form, but can also be demounted and remounted into another form.
- The harvesting costs are currently higher than demolition. However, the techniques and processes with harvesting will become more efficient over time, so it is assumable that prices will decrease.
- The value on material level is almost negligible on high development costs. This indicates that residual value must be safeguarded on element level to really add value in the long-term.
- In addition, it is expected that material prices will increase in the future because of scarcity and environmental impact. This stimulates the demand for harvesting even more, which will contribute to the development of this emerging market as well.
- The reuse of the structure and skin has resulted in lower building costs in 2022 compared to traditional development with 'virgin' materials. The difference is € 2.1 million, but is currently still outweighed by the additional costs in initial building costs and harvesting.

Ultimately it can be concluded that with the circular way of harvesting and reusing elements, a saving of € 330 K is realized after reconstruction. In addition, by incorporating a residual value and environmental costs, a saving of € 7.3 mio has been realized on the two layers of structure and skin, compared to the traditional way. This confirms the notion that additional investments on adaptability in the beginning with construction and harvesting do lead to higher benefits in the long-term, by lower construction costs and a residual value.

Table 9. Overview long term financial exploration DNB.

	Traditional	**Circular**	**Difference C-T**
1990 I Construction costs	€ 12.285.000	€ 12.899.250	€ 614.250
2021 I Removal costs	€ 680.000	€ 1.800.000	€ 1.120.000
2022 I Reconstruction costs	€ 6.175.260	€ 4.111.380	€ -2.063.880
Subtotal	**€ 19.140.260**	**€ 18.810.630**	**€ -329.630**
I Environmental costs	€ 144.507	€ 0	€ -144.507
2052 I Residual value	€ 0	€ 6.836.423	€ 6.836.423
Total	**€ 19.284.767**	**€ 11.974.207**	**€ -7.310.560**

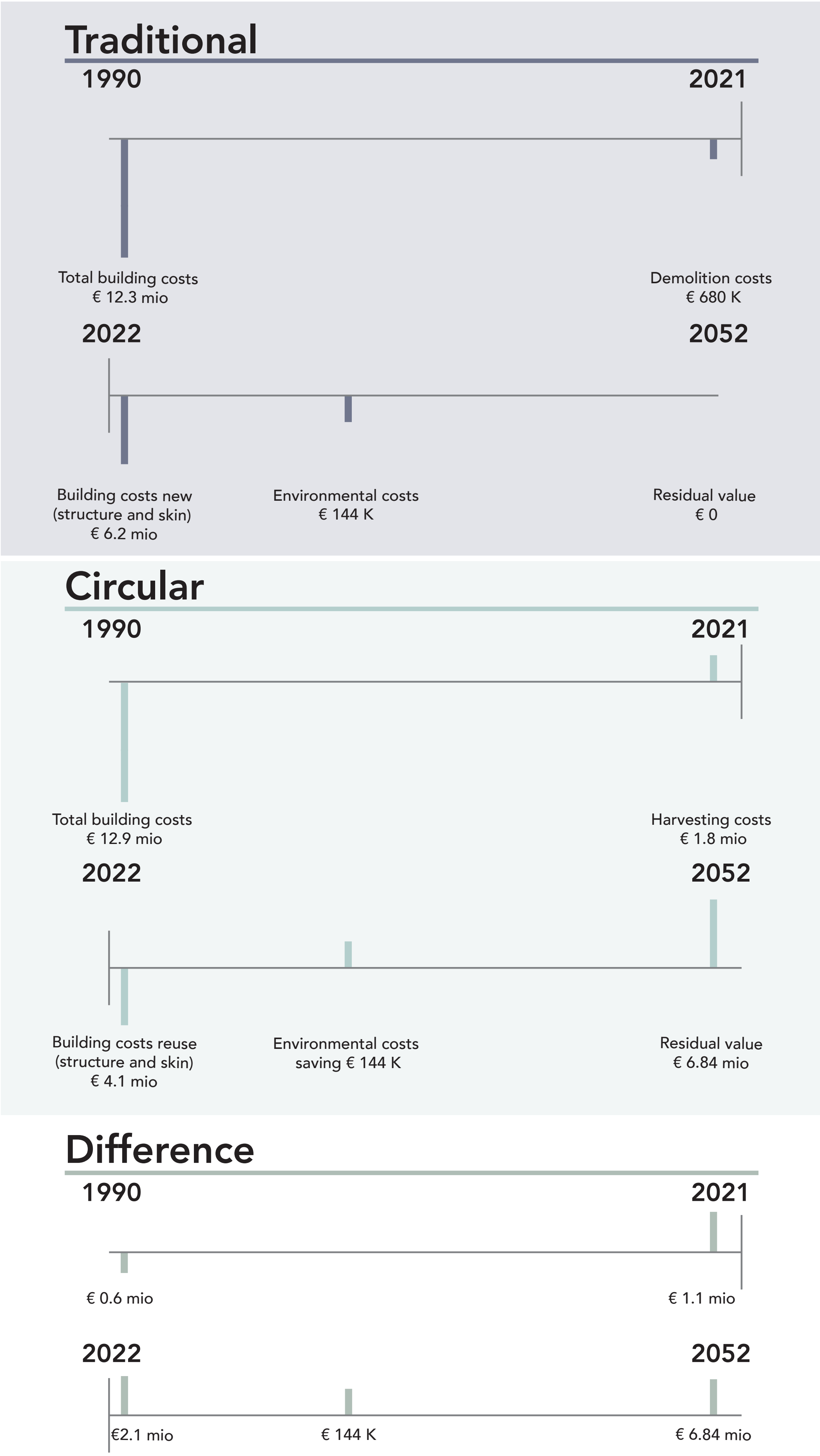


Figure 29. Overview long term financial exploration DNB.

3.4 Faculty of Aerospace Engineering

3.4.1 General information

The Faculty of Aerospace Engineering (AE) is located along the Kluyverweg 1 on the Delft University of Technology Campus in Delft. It is built in 1970 and designed by architect Geert Drexhage. The building counts 15 floors and is 79 m high, with a GFA of 21.088 m^2 (18676 LFA). The faculty consists out of several parts. The ground floor has additional height and is extended to the north with a low-rise part that allocates college rooms. The high-rise part mainly consists out of smaller rooms that are used as office or self-study spaces, and only the high-rise part will be taken into account in this case study.

It lies on the southern part of the Campus, while the most faculties are located in the northern part (above Kruithuisweg N471). The faculty buildings, together with a large part of the (empty) plots in the area are owned and managed by the TU Delft Campus Real Estate (CRE) department, which reveals a great potential for future Campus expansion.

The high-rise part has a horizontal corridor, with office rooms along the facades (figure 32). The elevators are located in the centre along the corridor on one side, while at both ends of the corridor staircases and toilets are located. There is a column grid that divides each floor into six segments. The facade consists out of light blue panels alternated with window strips horizontally.

Figure 30 and 31. Images of Faculty of Aerospace Engineering (TU Delft, n.d.)

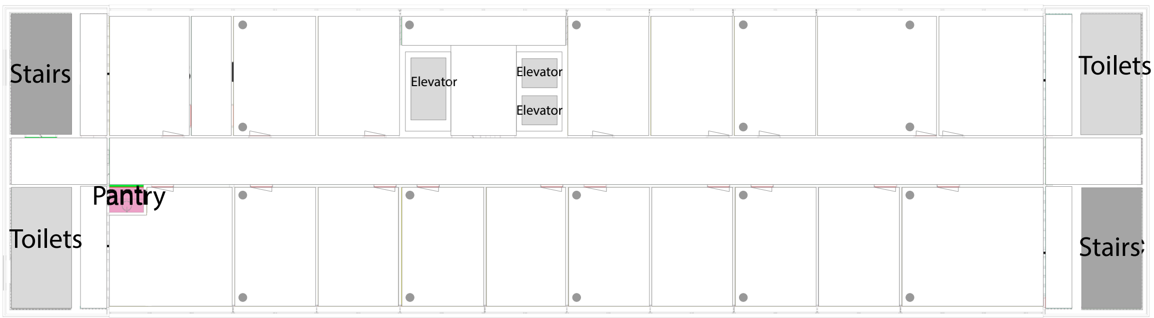


Figure 32. Floorplan of Faculty of Aerospace Engineering (TU Delft CRE, internal communication)

3.4.2 Interviews

This case serves as validation of all earlier findings, and will therefore be explored in a similar manner as with DNB. Informal meetings and one formal interview have been held with professionals from the TU Delft Campus and Real Estate (CRE) department, in which information is gathered about the case, but also about the organization and its ambitions towards adaptability and a long-term business case. The main findings can be found below.

TU Delft CRE as long-term owner

Asset Manager B mentioned that the TU Delft has a Campus strategy in which the long-term approach towards the whole portfolio is being discussed. Sustainability is one of the KPI's, yet additional goals should be formulated and monitored per building. This is something that is not yet in the DNA of the organization, but the organization is working on it, as Asset Manager A brought up.

One question was asked about TU Delft's ambitions regarding sustainability, and their most important sustainability strategy is to reuse as much as possible the materials and elements in the current portfolio. Still reuse is challenging with many older buildings that are not designed to be reused or adapted in the future. Also, the TU Delft chooses to focus more on flexibility instead of adaptability. Since they are a long-term owner for educational purposes, flexibility within the buildings will allow for different faculties and facilities to be easily switched. Flexibility is implemented not per room, but on a larger scale such as per floor, and by the use of over-dimensioning. Sometimes you can better standardize, and implement additional facilities to increase the usability for different functions. Also, it is mentioned by Asset Manager B that the value of adaptability is still in its infancy, and therefore the focus lies less on adaptability.

As a long-term owner, TU Delft CRE is experimenting with TCO calculations on three objects. *"But in the future, the translation from campus strategy to project should already take the TCO approach and thinking into consideration."* For now attempts remain explorative, since the TU Delft CRE considers this approach to be underdeveloped and in its infancy.

Lastly, TU Delft CRE is interested in using residual values for their real estate, but explained that residual value is for them mostly relevant on element level, because of its reuse potential for other buildings within their portfolio. Only seldom buildings are being dispositioned, which makes residual value on a larger scale less relevant.

3.4.3 Financial exploration

In the previous case it has been verified that the additional investments on adaptability upfront do lead to higher benefits in the long-term. This paragraph elaborates on a financial exploration over the long-term for the Faculty of Aerospace Engineering, in a similar form as with the case of De Nederlandsche Bank.

1970:

A new faculty building has been initiated. The building costs for this building could not be found within TU Delft CRE directly. However, the building costs total for an ensemble of buildings have been recorded, among which the Faculty of Aerospace Engineering was one (numbers validated by TU Delft CRE). Based on the GFA per building, the total has been divided per building, which leads to a building costs of € 5.958.482.

If the building would have been constructed in a more circular way, it is assumed that a building costs surplus of 5% is needed, similar as in the case with DNB. This would result in total building costs of € 6.256.406. This will lead to an additional investment of € 297.924.

Construction	Price / m2	Total
Traditional Building costs	€ 283	€ 5.958.482
Circular Building costs	€ 297	€ 6.256.406
Difference		€ 297.924

2021:
For the removal or harvesting of the building, the prices per m^2 of De Nederlandsche Bank have been taken as basis. The numbers of De Nederlandsche Bank are based on real-life propositions of third parties, and therefore assumed as realistic key figures. This leads to removal costs in the traditional scenario of € 1.750.304, while harvesting in a circular scenario comes down to € 4.639.360. It shows that in key figures, harvesting is 2.5 times more expensive than demolishing a building, but it includes the demounting, transportation and storage in total. This leads to a difference of € 2.889.056.

Removal	Price / m2	Total
Traditional Demolition costs	€ 83	€ 1.750.304
Circular Harvesting costs	€ 220	€ 4.639.360
Difference		€ 2.889.056

2022:
The reconstruction of the building in the same form (traditionally with all 'virgin' materials) can be estimated by indexing the building costs of 1970 to 2022. For this indexing, all yearly Consumer Price Indexes so far have been taken into consideration, and for 2021 and 2022 an average CPI of 2% has been taken. This leads to a reconstruction costs estimation of € 29.752.724. It is important to note that this estimation is rather basic and rectilinear, and it ignores many other influencing factors.

The circular scenario becomes even more difficult to estimate. Again, a surplus of 5% on the indexed building costs seemed the most reasonable approach, but this lacks the depth and the profound basis on real-life circumstances that was aimed to achieve here. The explorations would serve as validation for the fact that adaptability pays off in the long term, but the question is to what extent such validation is accurate if based on too many assumptions.

Data has been requested concerning documentation on the materials used, the current status of elements and previous renovation data. Unfortunately it appeared that there was no data available on these topics. A suggestion for TU Delft CRE is to investigate, map and monitor the portfolio and its embedded resources to create an inventory on which residual values and environmental cost calculations can be based. This can be executed internally or through outsourcing to a third party, but this goes beyond the scope of this research. It has been tried to derive data about costs from other references, but these results have been evaluated as not reliable enough, and therefore not valuable, due to the high amount of assumptions that had to be made. It is for these reasons that the researcher has decided to not continue with this exploration.

3.5 Explorative cross-case comparison

Even though the case study has been demarcated, there is always the given that buildings are specific products and choices have been made property- and location-specific. For this reason a comparison will be made to expose the underlying differences. In addition, a cross-case comparison allows to validate the findings of the literature concerning the adaptability features from a technical perspective. Table 10 on the next page provides an overview. The matrix shows an overview of the general characteristics, the ownership, but also the differences per building layer that have to be taken into account, and it is complemented by a textual elaboration of the most important differences below. Besides this qualitative analysis, a quantitative comparison has been performed to show the degree of adaptability on a numerical scale. Points have been ascribed per case if the conditions derived from literature have been met and the results can be seen in table 11.

General

The cases are all located within the Randstad area, and built between 1968 and 1991, which leads to a range of 23 years. It is noteworthy that especially offices built between 1970 – 1990 do not qualify for new users and have become vacant (Van der Voordt et al., 2007), but it is promising to see that some of the cases already have shown to be very suitable for transformation.

The height of De Nederlandsche Bank does not meet the 70 m as defined for being a tall building. However, an exception here is accepted by the fact that it is less than 10% deviation from the predefined height. In addition, it is verified by being an exceptional and demountable case that also allows for an in-depth exploration on residual values of elements. Since this case appears to contribute significantly to qualitative and explorative research results, it is justified to use this case.

Ownership

The ownership situation is strongly influential for choices regarding transformation, lifespan extensions, and other more specific real estate choices. All cases in this case study have a long-term owner or multiple long-term owners. This leads to an additional demarcation of the research. Yet within the long-term owner demarcation, the ownership situations still vary. The Lee Towers and De Nederlandsche Bank are owned by developing investors, which are private parties, who redevelop the object with the objective to keep it in own portfolio. Such parties perceive the building as an asset. The Faculty of Aerospace Engineering is owned by the TU Delft, which is a semi-public party. Their interest in owning real estate is different; it supports their core business, which is providing education. Park Hoog Oostduin is also owned by private parties, but consists out of private owners that have purchased an apartment for own housing. There is also an investor, which is Bouwinvest in this case, who partially owns it as an asset to rent it out. Here you see a division where the expenses lie; capital expenses have been financed by the investor, which have been partly earned back by selling apartments. The other part serves as own investment for which rents are received. The operational expenses are allocated to the owners of the apartments, and partly covered in the rents for Bouwinvest. This division makes it challenging, albeit almost impossible, to implement a Total Cost of Ownership or Circular Economy approach. As for the other three, redevelopment has been executed and ownership is being held at the same party, which leads to a total allocation of capital expenses and operational expenses with the owner. In other words, a Total Cost of Ownership or Circular Economy approach is possible to use here since all different costs and benefits arrive at the same party. This is crucial since it motivates owners to also think about lowering operational expenses by increasing the capital expenses upfront. Only this shift in thinking allows for a long-term and integral approach.

Table 10. *Cross-case analysis overview (own illustration).*

	The Lee Towers	Park Hoog Oostduin	DNB	Faculty of Aerospace Engineering
City	Rotterdam	The Hague	Amsterdam	Delft
Building year	1975	1968	1991	1970
Height	93 m	71 m	66 m	79 m
Number of floors	22	18	14	15
GFA	35.400 m²	49.380 m²	7.993 m²	21.088 m²
Building typology	Central core	Horizontal corridor	Central core	Horizontal corridor
Routing	Shared entrance and ground floor with shared facilities.	Elevators in the center along the corridor; two staircases at each end of corridor.	Case building as extension of initial building. Elevator shaft at the center, surrounded by staircases.	Elevator shafts decentrally located along corridor. Two staircases at each end of corridor.
Function before transformation	Office for municipality	Office for Shell	Office for DNB	Office / Educational
Function after transformation	Residential	Residential	Residential	Residential (student)
Dwelling sizes	38 m² - 127 m²	70 m² - 200 m³	*t.b.d.*	*t.b.d.*
Developer	Citypads & Bakkers Hommen Waerdevast	Pinnacle Property Developers	RE:BORN Real Estate	*n.a.*
Owner(s)	Citypads & Bakkers Hommen Waerdevast	Apartment owners & Bouwinvest Residential Fund	RE:BORN Real Estate	TU Delft CRE
Private or public party	Private parties	Private parties	Private party	Semi-public party
User(s)	Tenants	Tenants and apartment owners	Tenants	TU Delft
SITE				
	Owned by Citypads & Bakkers Hommen Waerdevast	Owned by apartment owners & Bouwinvest Residential Fund	Ground lease	Owned by TU Delft CRE
STRUCTURE				
• Construction	• Concrete loadbearing columns	• Concrete loadbearing columns	• Concrete loadbearing columns	• Concrete loadbearing columns
	• Wide floor slabs	• Wide floor slabs	• Wide floor slabs	• Steel beams
	• Loadbearing core	• Steel rack extension	• Loadbearing core	• Loadbearing decentral core
• Grid	1,8 m	1,8 m	Cylindrical (column-to-column 2,55 m)	4,4 m by 7,2 m
• Floor-to-floor height	3,75 m	3,5 m	3,75 m	3,25 m
• Span core-facade or corridor-facade	7,2 m or 10,8 m	7,9 m	7,5 m	5,1 m
SKIN				
• Demountable	Stacked facade, travertine stone.	Demountable per element.	Stacked facade, large panels.	Not demountable.
• Distinction short- and long-cyclical	Yes	Yes	Yes	Yes
SERVICES				
	Around core	Around corridor	Around core	Around corridor and along facade

Site
It is usual that the land is being purchased by the investing party to grant accessibility for (re)development on the plot. Yet many large cities in the Netherlands use ground lease or leasehold as an alternative to the purchase of land. In a ground lease, a person that buys a building or apartment does not buy the underlying ground. Instead, they sign a lease which gives them the right to use the ground for a certain period (Gemeente Amsterdam, n.d.). The owner pays the city a rent to do so. This is the case with De Nederlandsche Bank, which is located in Amsterdam. By not owning the ground but by renting it, differences occur in the financial model compared to land purchase. Ground lease is seen as an operational expense, while purchase of land falls under the capital expenses, and it is part of the assets on the balance sheet.

Because of the many differences in financial accounting that will hinder the overall comparability between the cases, it is chosen to not include ground lease as part of De Nederlandsche Bank. Instead, it is assumed that the building remains located on the current plot. For this case study the building is being approached as solid, yet the demountability will be taken into account with a first attempt of estimating the residual values. In other words, the building will remain located at this inner city location for now, but the benefits of the possibility to be relocated somewhere else will be taken into consideration within this case study.

Structure
The structure is the most determining layer that either makes or breaks the overall degree of adaptability of the building for an entire lifespan. Its typology, grid, dimensions and composition will have impact on all subsequent layers. This case study has already demarcated the typology by allowing two types that have many similarities related to flexibility. Yet one of the central core buildings has a rectangular floorplan, while De Nederlandsche Bank is cylindrical. This results in an absence of a rectangular grid, but instead the central core functions as loadbearing support together with the columns at the facade. This provides large open floors and flexibility in the allocation of separation walls. Besides, all cases are composed of loadbearing concrete columns with wide floor slabs, except for the Faculty of Aerospace Engineering. Original construction drawings have shown that here, steel beams have been used to support the floors, together with loadbearing walls and columns. As with the Park Hoog Oostduin case, there is a steel rack added to the concrete structure as extension for additional floor space, but it is not loadbearing and it holds onto the loadbearing concrete structure.

The grids of Lee Towers and Park Hoog Oostduin are 1,8 m, and as literature has suggested this grid size shows to provide the highest flexibility. The grid of the Faculty of Aerospace Engineering has a grid of 7,2 m along the long axis (with window grid of 1,8 m), but the grid in vertical direction shows to be 4,4 m, which is not aligned with the 1,8 m multiplication. The same goes for the cylindrical DNB tower; the distance from column-to-column is 2,55 m.

The floor-to-floor heights of Lee Towers and De Nederlandsche Bank show the greatest flexibility with its 3,75 m free height. Park Hoog Oostduin shows a height of 3,5 m, which gives additional quality to the current dwellings, but is not conform the 3,6 m as required height for offices again. Here you see that Building Decree requirements have become stricter. As for the Faculty of Aerospace Engineering, the height of 3,25 m shows the least flexibility for different functions.

Spans from core to facade range between 5,1 m and 10,8 m among the four cases. This seems logic since they vary in GFA and size, as well as in form and typology. The desired span as suggested by literature is only met in the Lee Towers.

Skin
Both the skins of the Lee Towers and De Nederlandsche Bank are a stacked facade, which means in order to demount a certain element, all elements that lie above it should be demounted first. This makes these types of skin demountable in essence, but it takes a lot of labour and therefore money to demount it. With a demountable facade, you want to be able to retract as small as one element to replace it for a certain change in function or desire. In this way, the skins of Lee Towers and De Nederlandsche Bank are not fully demountable as desired from a circular economy, but they are to a certain extent demountable compared to other real estate objects constructed in this linear economy. A benefit with De Nederlandsche Bank is that the skin consists of large panels, which has led to less needed panels and less repetition of the several actions needed for it. The skin of Park Hoog Oostduin consists of window frames and panels that can be easily replaced and are therefore demountable. Yet the Faculty of Aerospace Engineering has shown to have no demountable skin.

The distinction between short-cyclical and long-cyclical facade is based on Brand (1994) and the different lifespans. The long-cyclical facade part is often in line with the structure and grid, and is more difficult to alter than the short-cyclical parts, which are for example the window frames. This distinction is important with adaptability as you want to easily alter the elements with a shorter lifespan, and therefore it is important to think about this distinction already with the design of the facade. In the transformation of Lee Towers, this distinction was made clear when only the inner window frames were replaced, and the long-cyclical facade remained the same. For Park Hoog Oostduin, the whole facade was renewed, but there already was a distinction between the 1,8 m facade grid and the elements within, and it has been used to their advantage with the new facade as well. The facade of De Nederlandsche Bank consists of panels, but the long-cyclical elements of the panels are in good state to be reused, only the short-cyclical elements need to be refurbished to current standards. This case shows that even within panels, this distinction is very important with later interventions. The distinction is also clearly visible with the Faculty of Aerospace Engineering, where horizontal open strips alter with closed surfaces, in which the closed surfaces are often aligned with the long-term structure and grid. The effects of such facade choices are immense, and even though all four cases show to have this distinction to some extent, differences in transformations and eventually costs will prevail.

Services
Almost all services have shown to be located around either the core or the corridor, which is in line with what literature has suggested to be the most flexible. The only exception is with the Faculty of Aerospace Engineering, where part of the installations is located in or around the corridor, whereas installations such as heating are located along the facades.

Perception of adaptability
This thesis has adopted the definition of Schmidt et al. (2014) for adaptability, which is *"the capacity of a building to accommodate effectively the evolving demands of its context, thus maximising its value through life"*. But there can be different ways for accommodating this. The perception of how a building accommodates the evolving demands, by being adaptable, varies between some cases. With the Lee Towers, Park Hoog Oostduin and the Faculty of Aerospace Engineering, adaptability and flexibility are being dealt with as using an existing structure and as much of all other existing building layers for a different function by undergoing a transformation. The technical characteristics and how the different building layers are built up lie at the basis of this. But the starting point here is an existing building; A current and already existing state will be analysed per layer for its flexibility and adaptability and reused or adjusted where possible.

For De Nederlandsche Bank case, adaptability can be perceived differently within the same definition. This building can actually accommodate evolving demands by demounting and remounting its elements, and therefore returning in many different forms. If additional refurbishment costs and labor are not being considered, it can be stated that its degree of adaptability is the highest of all. Like the other cases, adaptability here is also perceived as reusing as much as possible from all layers, but this building is demountable in its origin, where the others are more solid in their form. This gives a new dimension in this case that is less prominently present in all current buildings and transformation projects. In addition, it allows for better capturing residual values since the elements can be valued separately. This understanding in the two forms of adaptability within this case study is crucial for correct interpretation of the results, and it can occur that results of De Nederlandsche Bank are not applicable to other buildings because of this additional dimension in adaptability.

Quantitative comparison

The above mentioned table and differences have been translated into a quantitative comparison, in which a point has been ascribed if the technical feature found in the literature has been met. The table shows that on paper, the Lee Towers is the most adaptable building if looking from a technical point of view and by only focusing on those features.

Table 11. Quantitative comparison degree of adaptability (own illustration).

		Points	**Lee Towers**	**Park Hoog Oostduin**	**De Nederlandsche Bank**	**Faculty of Aerospace Engineering**
City	Multifunctional area = Randstad	1	1	1	1	1
	Inner city location	1	1		1	
Building typology	Central core	1	1		1	
	Horizontal corridor	1		1		1
CapEx and OpEx lie with the same entity	Yes	1	1		1	1
	No	0		0		
Wide floor slabs	Yes	1	1		1	
	No	0		0		0
Grid measurement	1.8 m	1	1			
	Other	0			0	0
Span core to facade	5.4 m - 7.2 m - 9.0 m	1	1			
	Other	0		0	0	0
Floor-to-floor height	> 3.6 m	1	1		1	
	< 3.6 m	0		0		0
Demountable facade	Demountable per component	2		2		
	Stacked	1	1		1	
	Not demountable	0				0
Distinction long- and short-cyclical	Yes	1	1	1	1	1
	No	0				
Services around or in core	Yes	1	1	1	1	0.5
	No	0				
Total points			**11**	**7**	**9**	**4.5**

Conclusion of comparison

This cross-case comparison has been executed with the intention to expose the underlying differences. The differences are manifold, but it is attempted to point out the most important differences. First of all, ownership is an important aspect that influences choices being made on the technical layers of a building. Still Park Hoog Oostduin has shown to be a successful transformation, even though ownership is divided. The divided ownership is no burden since the focus did not lie on adaptability, but rather on flexibility. Also, with an existing building, the owner has less influence on the most critical choices to make in the structure, such as dimensions, materials and techniques. This means ownership situations become more critical with new developments, as those buildings have to be defined from scratch and will feel the influence of both CapEx and OpEx stakeholders.

When looking from the different building layers, there are small deviations per building, but this is conventional with buildings where each time different choices have been made in different phases along the process. The Lee Towers and Park Hoog Oostduin have shown to be adaptable in practice, and with this analysis it has also been compared by literature. Even though both have shown to be successful transformations, the Lee Towers scores higher than Park Hoog Oostduin. The difference lies mainly in the ownership situation, where Park Hoog Oostduin is owned by multiple owners, but also in the structure. The structure of Park Hoog Oostduin consists of loadbearing columns and cores, but the floors are not composed of slabs. Yet the design and measurements make it still flexible to transform. Lee Towers shows to have the ideal measurements to adapt nowadays, but also in the future. The MOR project (which stands for Modular Office Renovation), has implemented and validated the modular design of Lee Towers into a full scale prototype, which shows how flexibility and adaptability can be easily achieved. It demonstrates different dwelling types that are facilitated by a modular and flexible design (figure 33). As for DNB, it shows to comply with many technical features that makes it adaptable, as the case scores second among the four, and this is also enforced by being demountable in practice now. The only drawback that has been found in the score is the cylindrical form which is less flexible than orthogonal buildings. Lastly, the Faculty of Aerospace Engineering shows to be the least flexible of all, even though the ownership situation of a long-term owner is ideal.

The technical aspects found in literature that increase the adaptability of a tall building have been verified to a large extent by this comparison. Especially the chosen cases that have already been transformed and thus have shown to be adaptable can be regarded as a verification of the literature. This comparison has also shown that mainly the choices on grid and measurements in span and height have the most impact on all other subsequent layers and therefore on the overall adaptability.

3.6 Conclusion

This chapter has introduced the cases as part of the empirical part of this research. The cases have been elaborated separately and complemented by the findings of the interviews, which have resulted in useful lessons learnt of these transformations. In addition, the technical characteristics for improved adaptability have been validated in the interviews, and can be further extended.

This chapter has also shown the financial elaboration of De Nederlandsche Bank, in which the long-term overview has been given of costs and benefits. It can be concluded based on this case that with considering construction, harvesting and reconstruction, there is a slight difference in costs, in which the circular scenario is slightly less expensive. Yet this 2% cost reduction is not a substantial financial benefit. The actual benefits come later, when the environmental costs and the residual value are taken into account. This verifies the large contribution of residual value and environmental costs in the shift towards a more circular economy.

Unfortunately, the case of the Faculty of Aerospace Engineering could not validate the conclusions, so a careful notion needs to be taken by the fact that these findings are based on a single case only.

The cross-case comparison has shown that despite the similarities in typology, heights, and era of construction, there are underlying differences that have impact on the degree of adaptability. The differences among the chosen cases are found to be mainly ownership and technical variations in the different building layers. In addition, not all design choices are expected to be made for adaptable motives. Although the notion of case-specific and context-specific factors is in the nature of qualitative research, it is still important to consider this given carefully by interpreting the results.

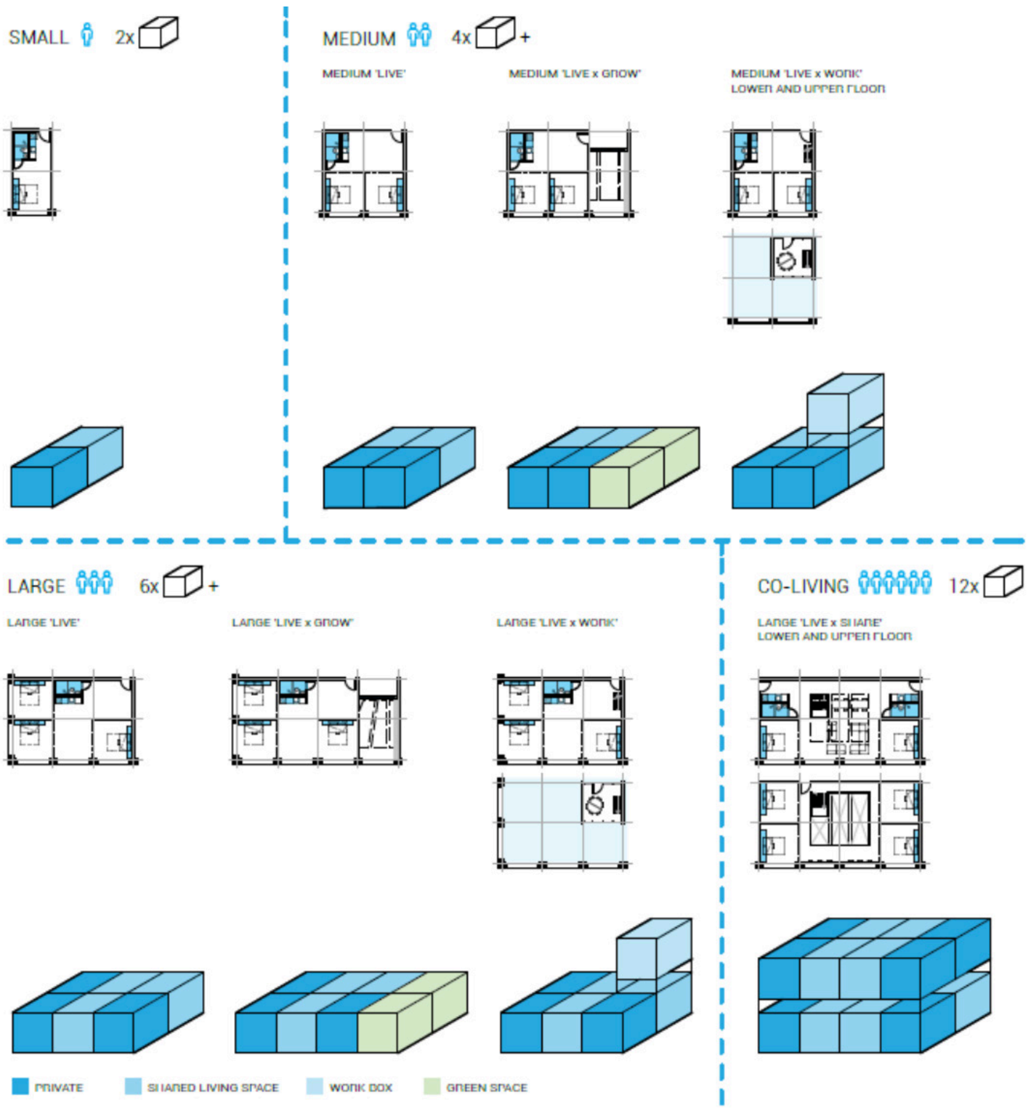


Figure 33. An overview of different dwelling types within the Lee Towers (MOR, 2019)

IV.
Long-term business case

IV. Long-term business case

This chapter will discuss the findings of the interviews with the other professionals that are not involved in one of the cases, but have been interviewed for their expertise in the built environment. These interviews have served for gathering information about where the built environment stands today in terms of long-term and circular approaches. The interview protocols have varied in themes that align with the interviewee's field of expertise and the related topic of the interview. The main aspects that will have an impact on the business case and have come forward during the interviews will be discussed here, emphasized by citations and elaborations of the participants.

The literature research has shown that for increased adaptability in tall buildings, the financial approach of the Circular Economy as distinguished by Brink (2014) is the most comprehensive. Cost items such as the residual value, (re)cycle thinking (a.o. reuse and refurbishment) and operational expenses are included in this approach, and these topics have been included in the interview protocols to discuss. The following paragraphs will dive into each of the most relevant discussed topics.

Lifespan

Asset Managers A and B (of the same long-term organization) mentioned that they work with a lifespan of 30 years in their financial models, because this organization assumes that in general after 30 years the services are in need of replacement. This intervention after 30 years is called the midlife renovation and it applies to the whole portfolio. Consultant A also confirmed that mainly a lifespan of 30 years is used in the current financial models.

The interviews clearly showed that the thinking in layers is making its way in the current way of thinking. Asset Manager A mentioned that this approach is more applicable to new developments, since *"the existing buildings have not been approached from this perspective, which makes it hard to perceive them now from this way"*. Consultant B also uses the layers of Brand (1994), but in addition he appeals to use own common sense as well since lifespans are different per function, sector and organization.

When taking a closer step into the different layers, especially the answer from Asset Manager B has been interesting. He mentioned that within the layers, the structure with the largest lifespan must be resilient for the long-term, so make it very flexible instead of adaptable or demountable. Another argument for this was the fact that the way of constructing or calculating the structure has not significantly changed the past century, which shows its resilient and fixed character. The other building layers are constantly subject to new standards and stricter regulations that are in line with the newest insights, and combined with their shorter life they are therefore always subject to refurbishments or renovations. So make sure the structure is flexible, and that the others (short-cyclical layers) are adaptable.

Another finding that came forward during the interviews is the distinction between different areas to take into consideration with an intervention. Asset manager B formulated the following: *"You should distinguish the different layers and analyse what is technically in good state and what not, but also what is needed conform new regulations and what is sustainable"*.

Here a triangle occurs between technical lifespan, internal ambitions, and external regulation, as can be seen in figure 34. Especially sustainability is a popular topic that actually currently often covers both internal ambitions and external regulation, and such sustainable measures can be best applied at the end of technical lifespans by refurbishment or replacement.

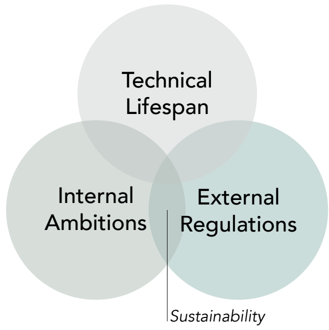


Figure 34. Different factors that influence interventions (own illustration).

Adaptability and flexibility

The distinction between adaptability and flexibility, as already mentioned by literature in Chapter 2, has been mentioned again by both Asset Manager A and B (of the same long-term organization). To them, flexibility is more important to focus on than adaptability. Since they are a long-term owner with a real estate portfolio to support their core business, flexibility within the buildings will allow them to switch among their needed facilities rather easily. Both flexibility and adaptability can be achieved within the building, by for example generic structural layouts, as well as other technical design features as mentioned in Chapter 2. The scenario of adapting to another function is however not of their concern, so adaptability and the ability to easily alter functions is less of a focus. Of course, this is a trade-off where each organization needs to position themselves in. Also, it is mentioned by Asset Manager B that the value of adaptability is still in its infancy, and therefore the focus lies less on adaptability.

Asset Manager B also emphasized that to him, flexibility is difficult to determine. There is a trade-off between flexibility and additional investment, in relation to the resulting benefits or quality. It can also be said that flexibility can be regarded as a means to increase circularity, through reuse and lifespan extension. Another end for which flexibility is used is the resilience of the portfolio.

Demountability (and BCI)

The ability to demount elements is regarded as fundamental for adaptability in buildings. Because if buildings are not designed for disassembly, it will require higher costs for recovering the reusable materials and elements. This results in smaller price differences between new and used materials, and with such small financial incentive, the preference often prevails with new materials. As already mentioned adaptability is still a means, and circularity or the circular economy is the final end (figure 35). It is the circular economy that stimulates constant

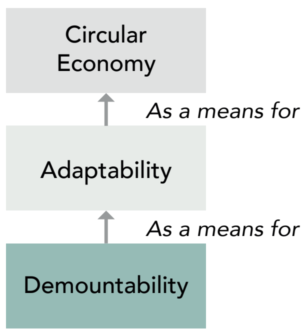


Figure 35. Different means to achieve a circular economy (own illustration).

retraction and reuse of resources, which is the most durable for all in the long-term. However, an important note to make is that not all circular approaches are always sustainable; there might be some externalities or downsides in a circular approach. But it becomes clear that in terms of materials and resources, a circular economy is desirable and for this increased adaptability is needed, and therefore there must be steered on demountability.

Especially Consultant B has been focusing on these topics, and especially the measurability and the financial translation in the circular business case. The Building Circularity Index, where he also worked on, is a first attempt to create a comprehensive assessment on demountability as one factor, and circularity as an end. The BCI assesses demountability from a technical point of view, by looking at four determining factors:

- Type of connection
- Accessibility to the connection
- Whether it has been crossed
- Form embracement

Choices on those four aspects are already made in the design, but have a major impact on the level of adaptability for the rest of its remaining life. It can therefore be used as an assessment for already existing buildings, but more importantly it can be used to steer on designs and future developments. In other words, the BCI can be a useful steering tool for increased adaptability in tall building developments. For this research, the four factors for demountability can serve as complementary to the set of technical feasibility aspects for adaptable (tall) buildings.

There is also scepticism about demountability, in the sense that elements with clicking systems or so-called dry connections eventually will be in need of refurbishment as well. Especially Asset Manager B emphasized this. By having specific profiles and clicking connections, the chance of a perfect fit is still small. This is where standardization might help in forming a solution, but this stirs up a new discussion where standardization is aesthetically undesirable. This research therefore mentions the criticism, but will not go further into this topic.

Residual value
The residual value remains a difficult topic with varying opinions. One of the main reasons for this is the lack of information on estimating residual values, which leads to the notion 'what we don't know, we fear'. This consequently leads to little evidence, which makes people even more hesitant. Evidence is also needed to convince large organizations, since *"such parties only act on the basis of facts"* (Consultant B). This vicious circle that is not broken yet is the reason why residual value as main principle for a circular economy is not widely adopted yet. That is why Consultant B emphasizes in his organization to strive for a financial residual value database of all products. In this way he believes the vicious circle can be broken.

Out of all the interviews, three interviewees mentioned that residual value is currently often regarded as a present, as a sort of coincidence in the business case. It is not calculated with upfront when the building was being built. This is what we ultimately want to be able to calculate, but out of all interviews, only Consultant B elaborated on a first attempt on how to perceive and calculate residual values.

There are mainly three different scenarios on element level. In the best case, the element can be reused 1-on-1. If it is demountable, in good technical state and no additional refurbishments are needed, the residual value is the highest. Secondly, it can occur that products need editing, processing or refurbishing. Reasons for this can be a reduction in quality and performance, by usage damage, or because of new laws and regulations. Lastly, recycling is the worst case. *"The recycling value is being reasoned from the London Metal Exchange, where raw materials are being traded. Then you know the minimal price for a material in that sense"*.

This exchange price must be corrected for transport, adjustment, electricity etc. On the contrary, the reuse value is being reasoned through the cost price instead of the scrap price. This is always element-specific and has not been elaborated any further. Also, every element may be in need of different alterations or processes.

An important link made by Consultant B is that elements in the shorter lifespans are more often perceived from the reuse value, but this is obviously linked to how simple or difficult it is to retract the products from the building. The higher on the hierarchy of layers, the more fixed the elements often are, which has its impact on demountability and therefore its residual value.

Consultant B also emphasized on the *why* for estimating residual values, and what there is to win. There are two main reasons:

- To say something about the way buildings or elements are included in the balance sheet and other accountings. This has impact on the way an organization depreciates, and how much. Consultant B emphasized that the largest gain is here to win, because then at the end of the day you unlock money that you don't have to depreciate, so you can invest it in something else.
- To support decision-making on project level in a financial sense by means of the residual value.

The following citation supports the why even more: *"With metals we see a recycling value between the 0% and 10% of the initial value. So actually it is strange that we depreciate a whole building. Actually from the investment in, let's say, aluminium window frames, you should not have to depreciate 10% of the initial price."* But for this statement to be acknowledged, and to be adopted by organizations and accountants, guarantees are needed.

"The way we determine it is by providing a range of what we expect the market will pay for it, and what the market should pay, and there often still lies a difference", as quoted from Consultant B. Yet this is not determinable for all products today. For example the services should then all be approached as recyclable and have a recycling value based on the material's value. With this approach, many assumptions are needed, accompanied by uncertainty.

Consultant A emphasized the following: *"At the same time I think we cannot fixate the residual value, it is also what we agree the value is. Also with mortgages and housing values, we apparently have agreed on a system wherein that will be the value"*. This indicates that a particular system is needed for valuing residual elements. This also lies in the nature of human; *"we find it comfortable to link a certain amount of value to it"*. So there lies a challenge in agreeing with each other what the most appropriate system will be, but this suggests that eventually we determine it ourselves based on technical and financial argumentation, and within the boundaries of current systems.

Other strategies

During the interviews, also other strategies relating to adaptability or flexibility came forward. One of them is questioning the actual need of space, because as Consultant A argued, *"the most sustainable is of course to not build at all"*. The amount of m^2 can be questioned and analysed, for example by analysing the trend in employees. This is in line with refusing, rethinking and reducing the amount of real estate, which is in line with the first 3 R's from Potting et al. (2016).

Asset Manager B emphasized the strategy of over-dimensioning and additional facilities where easy and cheap to do so, in order to create a flexible infill for each building. As he quoted: *"My requirement is make sure that something lasts for a long time, and most of the time it comes down to keeping it simple and flexible. And make sure you separate the different building layers from each other. If we apply this consistently, we are already going well."*

General improvements

In addition to other strategies for increased adaptability, general improvements for practice came forward that are worth to mention. First of all, the challenges for a long-term focus and a circular economy go through the whole development chain. Suppliers should also work on their product designs and how demountability is assured, together with choosing the appropriate materialization. Ultimately there is demand and supply for an adaptable real estate sector, but the supply of appropriate building elements are just as important as incentivizing the demand side.

Another important factor that was mentioned by both Consultant A and Consultant B is the need for a platform or building market place to create an actual market for re-used elements. As Consultant B formulated it: *"We need to make sure that more and more transactions will be done on a sort of building-market place or platform. In this way it will get more clear what the value of a product in a reuse scenario can be. The moment it will pay off, a market mechanism will evolve and you will also see that the price will increase"*. In addition, it could also function as a movement to join forces, to make this topic within the circular economy more discussable and eventually the new normal. So the market may be challenged. And also in the Program of requirements, you sometimes already see additional requirements regarding adaptability, however not to the desired extent yet.

One of the drawbacks of increasing adaptability is that you often rule out certain options during the design phase when you make requirements on for example demountability. This makes the inclusion of adaptability sometimes hard, as it may strike with other aesthetical or functional requirements. It also makes it difficult to convince other stakeholders. With adaptable or reusable elements, the price is often higher, so that is one point on which you have to convince others about its ecological and financial benefits. Secondly, there is often a settlement needed on other topics since the supply of such high adaptability standards is simply low at this moment in time, and not advanced enough to meet all requirements. Convincing is therefore twofold, if not manifold.

Business case

During the interviews questions were asked about the business case and to what extent alterations are adopted. Consultant A mentioned that *"you see more often that there is demand from the market to implement more circular aspects into the financial model"*. One of the circular business case aspects that Consultant B highlighted is the link with the layers of Brand (1994), with financial residual values. Consultant A could confirm this by stating that clients that have differentiated their business case in different layers have experienced it as positive.

It can thus be said that a long-term and circular business case is approached by and based on the different building layers of Brand (1994) that have each a different lifespan. There is a residual value at any moment in time, but it becomes most relevant when you plan to sell or renovate. The Capital Expenses (CapEx) and Operational Expenses (OpEx) should be aligned and be felt by the same persons held accountable. So with an additional investment (in demountability for adaptability) at t=0 you will have elements that are easily retracted and therefore better preserved in value, which leads to higher residual values than traditional at any moment in time (where a normal course of technical, functional and economical lifespan degradation is assumed).

A business case consists out of a combination of facts and assumptions, all translated into numbers that represent a certain value. But a business case comes with certain sensitivities, of which indexation is one. An example given by Consultant B was when calculating a residual value on material level, that indexation of materials is higher than for example the Consumer Price Index (standard inflation).

There are new assumptions to be made, sometimes for the long-term, which makes risk and uncertainty inherent topics to this transition. But on the other hand, a business case is adjustable and there are many buttons to toggle. This could open the discussion about the decisiveness of financial and non-financial argumentations. Perhaps the financial argumentation should not be the most important and decisive one, as you can toggle within a business case. Consultant A mentioned the following: *"Because you can always calculate your business case right, or to your own wishes, there is simply no trigger yet"*, and this suppresses the transition.

Perhaps the solution partly lies with the investors. Because of the lack of information and evidence, together with the long-term focus and accompanied uncertainty, the risk is considered higher compared to traditional developments. Consultant B has mentioned one case in which the Building Circularity Index calculation has been notarized and used as evidence for circular financing. Risk surcharges that are often used in Exit Yield and NPV calculations have been lowered as a result of this numerical evidence. This shows faith in creating good substantiations with which you may deviate from the traditional, as Consultant B said, but there still lie many difficulties in the way of accounting.

Another perspective on risk was mentioned by Consultant A. He suggests that *"you can partly price this risk, but you partly want to work on this and invest in this."* He recalled the intrinsic motivation of a person that can be deployed to invest consciously. An important distinction to make here is between the private investor and pension funds respectively. The latter are large organizations that function differently from angel investors or private investors.

Business model
The business models have not changed significantly; often still a product has been sold, not a service. Innovative business models are still rare in practice. But there is a new market emerging slowly, which is about urban mining. Urban miners want to harvest materials and elements in the future, and already make arrangements on it today. For the owner, guarantees are needed for adopting a residual value in the business case, as evidence and to reduce risk. Price agreements are being made based on market mechanisms, price development information and the value today, as well as assumptions.

Regulations and legislation (also CO2)
During the interviews, when asked about what could help in steering towards a more long-term focus and business case, two of the four interviewees mentioned that legislation could stimulate or even accelerate this. Consultant A stated the following: *"If we take the CO_2 emission into account in the whole story, the business case of urban mining and reused materials is much more attractive. And some sort of environmental tax is coming."* Here a CO_2 tax or levy is meant, meaning that the more CO_2 an organization emits, the more tax it is obliged to pay. Regulations could also work the other way around, meaning that less tax is paid by the ones that are emitting less CO_2, which is the case with reusing elements. Consultant B stated: *"With a demountable facade one could say if demountable, you may pay a lower VAT rate"*. In this way conscious choices and preference for demountable elements are rewarded.

General conclusion

The most important findings from the interviews have been summarized below and together can form the conclusion for this part of the research.

- A lifespan of 30 years has been used most often in the current practice.
- New developments are more often perceived from thinking in different building layers, such as the layers of Brand (1994).
- The structure with the largest lifespan must be resilient for the long-term, so make it very flexible instead of adaptable or demountable.
- With every intervention, it is important to find a match between the technical lifespan of the existing element, the internal ambitions of the organization and the external regulations.
- (Long-term) organizations differ in prioritizing either flexibility or adaptability in their real estate.
- The ability to demount elements is regarded as fundamental for real estate adaptability.
- Demountability depends on the following four aspects: (1) type of connection, (2) accessibility to the connection, (3) whether it has been crossed, (4) form embracement.
- Standardization in clicking and mounting systems is needed for large-scale remount and reuse possibilities of elements.
- The little amount of information and on upfront estimation of residual values can be regarded as main causes for slow adoption in practice.
- Suppliers should also work on their product designs and how demountability is assured, together with choosing the appropriate materialization.
- An actual market for re-used elements is needed, by for example developing a platform or building market place.
- Risk can be regarded lower with an adaptable building, so it should become possible to assess the demountability or adaptability, and to use it as evidence for a lower risk profile.
- Innovative business models are still rare in built environment practice, but the market of urban mining is upcoming.
- Legislation could incentivize the reuse and demountability of building elements better.

V.
Synthesis

V. Synthesis

The goal of this research was to deliver conditions and new insights for an improved long-term business case, that takes adaptability and its benefits better into account. Therefore this chapter will elaborate on the main findings that relate to the long-term business case. Of course, this topic touches many fields and is locked in the current system, but this synthesis captures both technical and financial conditions, as well as suggestions for the process and in the larger picture of the whole system that needs adjustments. Lastly, a roadmap to the long-term business case has been elaborated.

Technical

See table 12 for the extended version of the technical features that increase the adaptability of a tall building. Note that the findings of this part of the synthesis are demarcated for tall buildings and their office typologies specifically, while the other findings apply to both tall buildings and low-rise buildings, and the real estate sector in general.

- Demountability should be ensured for all layers of a building except for the structure. The structure will remain and needs to be flexible and generic, while all other layers need to be adaptable by being demountable.
- For increased adaptability, it is useful to make a distinction between elements that are most subjectable to change and least subjectable to change.
    - Most subjectable to change: Design with as little resources possible for easy alteration.
    - Least subjectable to change: Design as demountable for future use at another location

Table 12. Complemented overview of features to increase adaptability

Legal	
	Land-use plan flexibility.
	Building Decree compliance.
Technical	
Structure	Generic and flexible lay-out: a central core or horizontal corridor.
	Free floors; Wide floor slabs loadbearing in two directions.
	Grid measurement of 1,8 m preferred.
	Small span core to facade; 5,4 m - 7,2 m - 9,0 m.
	Floor-to-floor height 3,6 m.
	Possible for horizontal floor extensions.
	Design the structure as flexible, not adaptable or remountable.
	Keep core generic, by including only the essentials and excluding function-specific facilities from the core.
Skin	Design the facade as demountable and adaptable.
	Keep distinction between long-cyclical and short-cyclical facade.
	Make distinction most subjectable to change and least subjectable to change.
Services	Locate services around or in the core.
	Never integrate services with structure.

The following conditions do not specifically apply to tall buildings, yet tall building cases have been used for retrieving these conditions.

Process

- Adaptability is inherently connected to the design of a building. Therefore an important condition is to incorporate adaptability in the design phase already. Being aware of the value that materials in a building can still have in the long term changes the design of a building. In this way, better anticipation on maintenance occurs and in this way preservation of the elements is better assured.

- The design phase is initiated and steered by the client, and therefore the degree of adaptability mainly depends on the client. It is important that the client establishes circular ambitions and requirements at the beginning of a project. This will form the main thread throughout the process, and in this way adaptability can be assured.

- Investors, who have a longer-term scope than the suppliers or adivsors, are regularly involved in developments relatively late. The investor buys the project, but is not involved in the design choices and planning; only the developer who is more transactional oriented and uses a short-term financial scope is. When the investor is involved early in the process, it becomes easier to make the shift from costs to long-term value. Early involvement of an investor can thus help stimulate sustainable (financial) choices.

- A condition for increased adaptability is to incorporate guarantees by checks and balances along the process and operation period by Service Level Agreements with other parties, so that the performance level, quality level and therefore its future value are guaranteed.

Financial

- Consider a building consisting out of layers with different lifespans. The higher adaptability is achieved within the building layers, the larger impact on the building and on the built environment as exchanging network. A long-term business case should also be divided according to the different building layers for increased accuracy on lifespan, renovation and maintenance. A suggestion is to use the layers of Brand (1994).

- A condition for increased adaptability is that Operational Expenses and Capital Expenses lie with the same entity with a long-term perspective. It is not possible to fully appraise whole life costs if different cost components, both short- and long-term, are the responsibility of different entities. Only this long-term perspective allows to see the financial benefits of adaptability in lower transformation costs, lower exploitation costs and better preservation of quality of elements.

- Financial residual value should be included in creating the financing conditions. The risk profile of an adaptable building is demonstrably lower. Yet first there needs to be agreed on a valuing system, based on the supply and demand of elements in the database or market place.

- Construction costs should be calculated per building layer. This because the lifespan differs and it can lead to more accurate residual values. This subsequently leads to lower and more accurate depreciations, which unlocks money that can be invested elsewhere.

- This thesis advocates for adding the MPG to the long-term business case, so that it becomes an integral part of the feasibility studies within the traditional financial approach. In this way choices cannot only be based on the economic impact, but they can be made on ecological impact as well.

Broader field

- Adaptability can only be increased by both stimulating the demand side, and by redesign from the supply side. An important condition is for suppliers to improve their product designs and how demountability is assured.

- Another condition needed to stimulate the adaptability is to create a database, market place or platform to exchange harvested materials. In this way, the value of elements can be better estimated as close to reality, which subsequently leads to more transactions and an actual market for re-used elements can be created. This database should also be provided with more and reliable information from the suppliers about its value. It is very important that such information will be shared transparently throughout the whole sector.

- Another condition for better implementation of adaptability and its financial benefits lies with a change in the fiscal system, for example a shift in taxes from labor to 'virgin' materials and pollution. This seems not realistic on the short term, but the topic has gained attention and is therefore worth to mention in this thesis.

- An important condition that stimulates circular principles in general is that tools and labels should be used as steering instruments upfront, and not as assessment instruments afterwards.

- A condition for the implementation of residual values is that the government must start the discussion with relevant market and valuation parties to remove tax restrictions where possible that now disincentivize the adoption of residual values and the long-term thinking. On the contrary, the government must convert them into financial incentives to enable the moral and socially desirable choices for adaptability.

- Another condition for increased adaptability is the need for a wider implementation of material passports. Material passports serve in creating value by recording the value of materials over time, how it is constructed and where it originates.

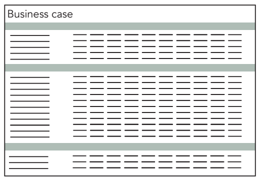
For the latter conditions, legal obligations are needed. The national government can take a crucial role in the transition towards a more long-term and adaptable built environment, by establishing requirements on the usage of material passports and by obliging assessments and minimal scores on adaptability. By establishing legal conditions or requirements related to adaptability, demountability and the reuse of resources, the transition can be accelerated.

Business case:

This paragraph will highlight the different steps that can already be executed to make a shift towards a more long-term business case. The design of this roadmap is applicable to all new developments, and is not limited to a certain type of function or typology.

0. Traditional

The roadmap takes the traditional business case as starting point from which to evolve. It is believed that the circular economy will also slowly arise out of the traditional, linear system.

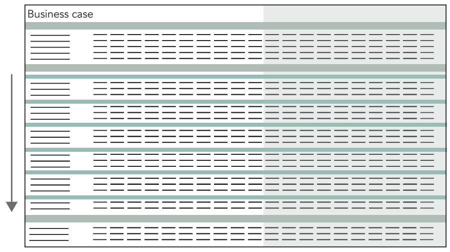


1. Expand horizon

The first step is to expand the horizon by calculating with a lifespan longer than 50 years. This enforces the long-term thinking from the model, and stimulates a different perspective on decision-making. The goal of this step is to take into consideration multiple (shorter) lifespans and the transformations in-between.

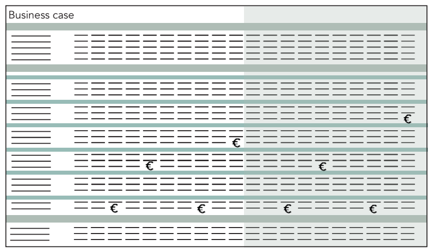
2. Separation by layers

As already mentioned in this research, an important step is to distinguish the separate layers of a building in the business case as well. A distinction in Site, Structure, Skin, Services, Spaceplan and Stuff has been taken as example here. Important is to distinguish as many cost items as possible per layer. Its goal is that it leads to more detailed and therefore realistic approximations and insights in total costs and benefits over its lifespan.



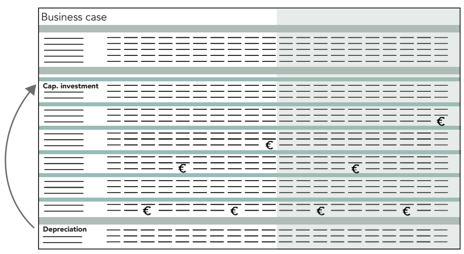
3. Include residual values

The third step is to allocate residual values on each layer after the end of its lifespan, since in a circular economy it is assumed that resources and materials always remain to have a value. This value has a positive effect on the total investment made over time. In other words, the goal is to incorporate the value after use in advance to decrease the total investment.



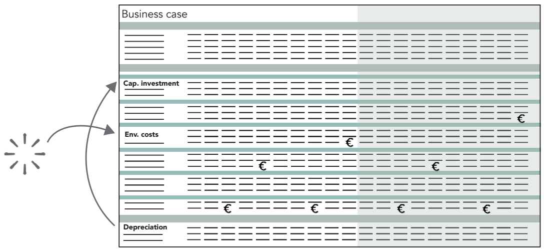
4. Adjust depreciation method

By including a residual value, the depreciation method can be adjusted by depreciating the cost price minus the residual value. This leads to lower depreciations than traditional, which unlocks money that can be invested elsewhere or in the same project. Depreciations can also be lowered by taking longer lifespans than traditional.



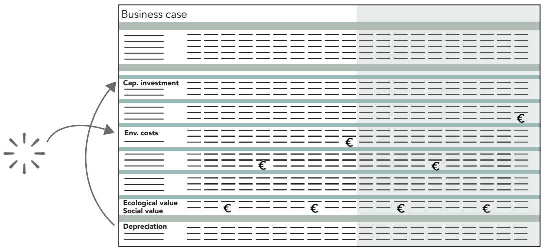
5. Include environmental costs

Besides the financial costs, the environmental costs should also be included in the business case for an integral and realistic assessment wherein the potential of adaptability is better visible. For this, the existing tool of MPG can be used to form an integral part of the long-term business case. It is also suggested to take into account the environmental costs of reused materials and their origin. The main goal of incorporating environmental costs is to create a model for decision-making based on both financial and environmental performance and impact.



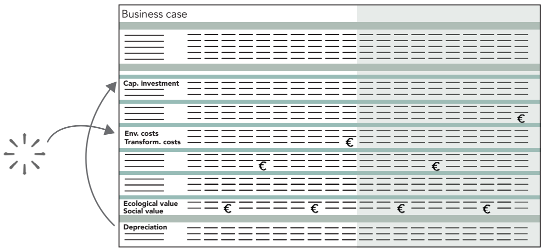
6. Include social and ecological value

Eventually, for a comprehensive approach, the social and ecological value created by the building should also be taken into consideration. Here, value can be regarded as impact being made and quantified into euros. However, further research is needed on the exact implementation of such aspects.



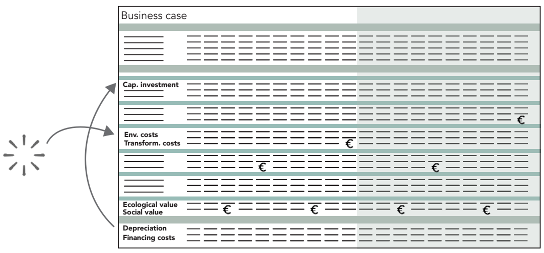
7. Include transformation costs

In a traditional business case, the cost item of replacement costs is already used, often for renovations and maintenance. However, with adaptability, transformation costs are a new cost item that replaces the renovation costs. Transformation costs are lower in the long-term for an adaptable building because of its adaptive capacity, and by including this cost item, it should become visible in a long-term business case.



8. Adjust financing approach

The costs of financing are an important part of the business case. In a long-term business case, a lower interest rate can be used since an adaptable building has a significant lower risk because of its adaptive capacity. This leads to lower costs for developing adaptable assets. This step does not influence the financial model itself, but rather the approach towards financing adaptable projects. Still it is believed that for a comprehensive overview, the financing costs need to be mentioned in this roadmap as well.



In this way, the long-term business case eventually includes all costs and benefits, and has monetized all negative and positive impacts into costs or benefits. Hence, the business case can be used for insights in and decision-making on design and process choices, and ofcourse steering on adaptability can be better defended and explained.

VI.
Conclusion

VI. Conclusion

This research has been written with the aim to gain knowledge on adaptability and how it can be better implemented in new developments and redevelopments in practice. The underlying goals for this research have been the following:

- to make the financial benefits of adaptability visible and workable.
- to contribute to the decrease of vacancy (of tall office buildings) in the future.
- to maximize the value of resources that are already invested in the current real estate stock and to minimize the usage of 'virgin' resources and the emission of CO_2.

For this, a literature research has been conducted on adaptability to identify the main aspects that improve the adaptability of a building. These findings have been taken into consideration in the empirical part, wherein real-life cases have been studied and interviews have been held with stakeholders and professionals in the built environment. This chapter summarizes the answers to the sub-questions and the main question, as well as discussing the process and presenting recommendations for further research.

6.1 Research questions

The main question of this thesis was: *"What business model and financial model are most appropriate for real estate organizations to achieve increased adaptability in tall buildings?"* In order to answer this, the four sub-questions will first be answered.

Sub-question 1: What features have to be incorporated in order for a tall building to be adaptable?

This question has been posed to find out in the literature study what factors or characteristics have influence on the adaptability of a tall building. These findings have later been complemented with additional features that occurred during the case study.

To be adaptable means a building can adapt at the end of its functional lifespan to another function, where a new functional lifespan can start off. Therefore, a building needs to be seen in different layers that are independent from each other, meaning each element and layer is adjustable or replaceable without affecting the other layers. This is a fundamental feature that needs to be taken into account in the design phase already.

Secondly, it was mentioned in both the literature as well as in several interviews that demountability is a fundamental feature and a means for achieving adaptability. The more a building is composed out of demountable elements, the easier it is disassembled and the more common adaptable building practices and reuse of elements can become.

Table 12 in the previous chapter has shown an overview of the most important features found in the literature study, which have been categorized in legal and technical characteristics. The structure shows to have the most features and is at the same time the most critical layer for the overall adaptability of a building, also because of its longest lifespan and it serves as the basis for all other building layers to be connected to. During the interviews with stakeholders of the cases, additional features were mentioned that hindered the transformations, which are adopted as lessons learnt and have been added to the framework.

First, the structure should not be always be adaptable, but rather be flexible and generic to allow different functions. All other layers need to be adaptable by being demountable. A second addition is to keep the core generic by including only the essentials and excluding function-specific facilities, but to locate these in the flexible spaceplan lay-out. Thirdly, besides the distinction between long-cyclical and short-cyclical, there is also a distinction possible for most subjectable to change and least subjectable to change. Sometimes these two perspectives align, but this not always applies. It therefore serves as an addition to the current body of knowledge found in literature.

Sub-question 2: Which approach for a long term lifespan (for an adaptable building) can be best used?
As already mentioned with sub-question 1, a building should be perceived by different layers that each have a different lifespan. Buildings should not be considered as being one object, but as the sum of different objects. For this, the layers of Brand (1994) are the most comprehensive and close to practice to implement. Brand (1994) mentioned ranges in which the lifespan may vary, and this has been validated by several interviewees. Ranges are used since lifespans depend on the materials used, as well as the level of maintenance executed over its life. Therefore, there is no single approach for estimating the lifespan of an adaptable building, but an answer can partly be given by providing a comprehensive overview of the influencing factors. In this way, the absence of a comprehensive approach is thus an answer to the sub-question. In general, the following can be said:

- The longer the lifespan, the more the focus lies on flexibility instead of adaptability or demountability.
- The longer the lifespan, the more fixed the elements and connections often are.
- The longer the lifespan, the lower its residual value on element level will be (but residual value lies more on the whole ensemble).
- The longer the lifespan, the smaller the differences between lifespans among different functions are.

Lifespans do not only differ per building layer, but they also differ per function and the degree of usage that comes with it. Besides, the differences among functions are larger in the short-cyclical layers (services, spaceplan and stuff), while the differences are smaller in the long-cyclical layers (structure and skin).

All in all, estimating a lifespan per layer requires many assumptions to be made, which has resulted in slow adoption in practice. Still it is needed for the step towards a long-term business case where residual values are included. Estimating a longer lifespan leads to lower depreciations, which is one of the main financial benefits of adaptability. By implementing and experiencing it, more evidence and knowledge is created which is crucial for the sector to develop itself in a more long-term and circular way.

Sub-question 3: To what extent is adaptability taken into account in the current financial model?
For this question, the interviews have been used to gather insights about the current situation regarding adaptability and the financial models. At some points, the findings from the interviews align with the literature findings.

As mentioned in the literature, approaches such as Total Cost of Ownership and Life Cycle Costing are still not widely adopted in the built environment, because of lack of fiscal measures and lack of reliable and relevant information and data. This has also been confirmed in the interviews. Also, demountability has gained no real recognition yet in new developments, as these ideas on demountability as part of adaptability and durability are brought up more by architects as design principle than by clients as requirement.

The problem lies in the system in which a separate entity (a developer) with no intention to own the building is developing it with a focus on sale in the short-term. It is this stakeholder that must be aware of the benefits of adaptability. This can be achieved by involving the investor or future owner earlier in the process.

In a traditional financial model, only the additional investment costs for adaptability are taken into account in the construction costs, without considering financial benefits. The interviews underpin this by mentioning that often transformation projects have been approached as new objects in financial models, without taking benefits such as residual values or reused elements into account. This can be ascribed to the fact that traditionally a building is developed for one lifespan and one function, which makes adaptability and demountability an irrelevant topic for only one function. Legislation and evidence for such valuations are necessary for them to take a step further.

The cases of this graduation research have also demonstrated this low adoption of adaptable approaches in the financial model. Only DNB has approached their financial model according to the layers of Brand (1994), which allowed for the comparison of building costs with new or reused elements. In addition, different residual value calculations have been performed, but are not adopted in the business case yet. In this thesis the residual value has been estimated and calculated over a longer period, and has confirmed that by adopting a residual value a business case can become more attractive. By executing more of such residual value calculations in the near future, it is hoped that the evidence and knowledge base increases, which incentivizes long-term owners even more.

Literature mentioned that traditionally a lifespan of 50 years has been taken, while the interviewees mentioned a lifespan of 30 years has been taken in current financial models. Still, the long-term perspective beyond 50 years is not taken into account. This thesis suggests to extend this lifespan in the financial model beyond the 50 years, in order to forcefully having to calculate with adaptations in functions.

All in all, it showed that small explorative steps are currently taken in the market in their financial models and towards adaptability. These small steps have often been taken based on own ambitions and drivers of the organizations. To contribute to the body of evidence, and to show that it is possible and beneficial, but still with risk and uncertainty.

Sub-question 4: How can the financial model be changed so that adaptability benefits and costs are taken better into consideration?

The answer to this sub-question has already mostly been elaborated in chapter 6 Synthesis, as it elaborated on conditions and a roadmap proposal for an improved long-term business case in which the value of adaptability is better included. As a recapitulation, the eight steps that can already be implemented in the current financial model are:

1. Extend the investment period
2. Separate the investment over building layers
3. Include residual values
4. Adjust the depreciation method
5. Include environmental costs
6. Include social and ecological value
7. Include transformation costs
8. Adjust the way of financing

Main question
For this thesis the following main research question has been formulated:

"What business model and financial model are most appropriate for real estate organizations to achieve increased adaptability in tall buildings?"

In order to answer this question, the business model and financial model will be elaborated separately.

There are different traditional and more circular business models currently used in real estate development. In general, a shift from ownership to services is recognized among the more circular variants. Here again, the relevance of ownership emerges. Still both literature and empirical findings underpin the lack of knowledge on development of value over time with leasing business models and other more circular business models.

It can be said that for each layer, a different business model could be applicable, based on the costs and benefits and processes needed. It is project-specific to determine what business model is most reasonable to use per building layer. Yet when considering adaptability in a new development in general, it touches the two business models of Resource Recovery and Product Life Extension, as mentioned in the literature. It is believed that by focusing on one of the two models on a project by developing a strategy for it, adaptability is ensured in the development which could lead to financial incentivization as well.

Unfortunately, this thesis was not able to gather empirical data related to the main question on which business model is most appropriate. More specifically, in the chosen cases no circular business models have been used, and the stakeholders and professionals interviewed were unable to provide information on this topic. A more detailed explanation will be elaborated in paragraph 6.2 Discussion.

As for the business case, this research has demonstrated that the traditional business case is able to extend and evolve towards a more circular and long-term business case. Therefore, for the question what financial model is most appropriate, it can be answered that the traditional model is still the most appropriate basis, but is in desperate need of alterations. A proposal of alterations has been mentioned in chapter 6 Synthesis.

6.2 Discussion & limitations

6.2.1 Discussion

It became clear during the research that the chosen topic of adaptability and a needed shift in the business case has been found very relevant by many organizations and professionals in the field. The demarcation of tall buildings has come from a personal interest in tall buildings, but also from the fact that large amounts of resources and materials are needed for them. In this way, by focusing on tall buildings, it was believed that the results of this thesis could contribute to the problem more significantly, because of the extremes that come with tall buildings. Looking back, it is believed that the demarcation has also led to limitations for this research, which will be further elaborated below.

The chosen method has been qualitative and explorative in its origin, which was most suitable for the topic of the research. This was also noticeable during the interviews and the data collection. In some parts, there was more information retrievable on soft values rather than on hard and financial values. This has led to different levels of quality per case.

Also, the interviews with architects, owners, consultants and asset managers have resulted in different perspectives that should be noted carefully. For the case of Lee Towers and Park Hoog Oostduin, it has resulted in more building and technical data retrievable, and less financial data. The depth of financial data has only been achieved within the case of DNB.

The perspective of the owner was safeguarded by including an interview with several owners and asset managers, but due to several different (unforeseeable) reasons some interviews did not reach the desired depth or did not take place at all.

Case selection
The cases for the case study have been selected based on the demarcation of tall buildings and technical aspects found in the literature research for increased adaptability. However, during the empirical research, demountability became more relevant for adaptability, but only one case was actually demountable. Looking back it is believed that a case study with demountable cases could perhaps have contributed more towards the posed problem than the case study of this research.

This thesis has been demarcated by focusing on tall buildings specifically, and by looking at transformations from office to residential. Tall office buildings often have a central core or horizontal corridor typology, which have resulted as the most flexible lay-out types in the literature and therefore seemed reasonable to continue with. However, most office transformations have been executed with smaller office buildings. Here, many potentially useful cases could have been missed by focusing on buildings higher than 70 m.

The choice for transformations was made based on the fact that transformations have shown and proved their adaptive capacity. In this way, it was assumed that adaptability was a main focus that has been steered on, and that was taken into account for the future as well. However, during the interviews it became clear that with three cases, maintaining the adaptability for the long-term was never their focus or ambition. It was only transformed once, and no other future functions have been taken into account. There was not steered on adaptability, which made part of the interview less useful since depth could not be reached on this topic.

Another important note to mention is that adaptability cannot be taken into account to the same extent with transformations as for new developments; there lies an important difference, since the design phase, which means the phase with the most influence on adaptability, has already passed. This thesis has focused on transformations in which there has been looked at various adaptable building characteristics, but still their adaptive capacity can be lower than for new developments. Based on the results, it can be questioned if the design phase would have been more interesting to research than the transformation phase.

The different cases have been distinguished by different phases over time; *Adapted, Adaptable* and *Will be adapted*. The *Will be adapted* case of the Faculty of Aerospace Engineering has contributed the least, because of too little available information and data. Instead, assumptions could have been made, yet this made the case less representative and less based on real-life circumstances. Still it was possible to continue the research based on the other two phases, which was a benefit of the diversification. Still for the financial results of DNB, the majority of data used are based on case-specific data and some assumptions.

Looking back, the different phases have perhaps been too broad to all take into account for a graduation research, within the restricted time planning. For a next time, the same phase could have been taken for a case study. In this way, the results are better comparable, the differences in interview approaches would be eliminated, and depth could have been reached more easily.

Results
Because of the different levels of depth and quality in the case study and interviews, the results also vary. The cross-case comparison, lessons learnt and interview findings are more qualitative, while only the financial exploration covers the quantitative part of this research. All findings gathered from literature and empirical research have been reflected back on the posed problem and research questions and subsequently have been synthesized in the most objective way in chapter 5. The relation between the sub-questions and the methods for gathering the answers worked well, and answers have been provided. However, difficulties occurred when translating the answers of the sub-questions to a general answer on the main research question. A large gap has occurred in the part about the business model, which has not been covered well enough in the sub-questions and has therefore lost focus in the empirical part.

Note that the proposed conditions for a long-term adaptable business case are a first attempt, and have not been validated from different perspectives in the field yet. Besides, other externalities could influence the financial benefits of adaptability as well. Therefore, by adopting these conditions, the financial benefits are better measurable and visible, but they do not guarantee an increase in financial benefits. This still depends on design and market characteristics.

6.2.2 Limitations
The first limitation of this graduation thesis is the lack of data on certain cases that could not have been anticipated. The planning was to have an interview with the owner of each case, since the perspective of the owner seemed the most valuable, and a minimum of two interviews per case. Even though all interviewees had agreed on doing the interview, not all interviews have been executed due to ignorance from the interviewee. This has resulted in less input and data, which makes the results less reliable. For the case of the Lee Towers, only one interview has been executed, which means the results are derived from one perspective.

The interviewees of chapter 4 have been selected based on their alleged expertise on real estate and financial models. No rigorous criteria have been used, which has resulted in different backgrounds and perspectives towards the built environment. This can lead to certain biases from the interviewees in the answers provided. In addition, the results cannot be related to a single professional perspective.

Lastly, the limitation of Covid-19 had influence on the process and the final results. Because different forms of lockdowns had been called out over the year, this thesis has been written mainly from home. It could be a realistic assumption that during the process, the amount of feedback moments and sparring moments have been less than regular. In addition, almost all meetings and interviews have been held online. This lowered the threshold to participate in this research, which may have contributed to a higher number of first attempts that led to a confirmation to participate. However, along the process the threshold was also low for some interviewees to withdraw from the participation.

All in all, it resulted in a time-consuming process of getting in contact with the right person, planning the interviews and actually preparing and performing them. The graduation organization made it easy to get in contact with professionals, and with internal stakeholders for the case of DNB. Since DNB is a case of the graduation organization itself, the gathering of data and information went faster and more effective than with the other cases. This may have influence on the amount of data and results of this case.

6.2.3 Reliability and usability
The reliability of this thesis has been guaranteed during the case selection. The chosen cases have similar characteristics and typologies, which increased the reliability of findings for tall buildings and these tall building typologies specifically. However, the results are based on the four cases only, meaning that especially the technical findings need to be validated for other typologies as well to increase the applicability. Also note that this thesis has only covered cases from the Netherlands, which means there might be influences involved that are context-specific.

For the empirical part, information has been gathered through a case study and interviews. The interviews and results of professionals concerning the long-term business case are based on personal views of experts. If this research would have been conducted again in a similar way, yet with other interviewees, the results of this research could have been different, which decreases the validity of this research.

In addition, the interviews have been prepared by different interview protocols because of the interviewee's different backgrounds. This means not all interviews could be easily compared to each other; only on some topics there was overlap, which have been mentioned where applicable.

The results of this thesis are partly based on the findings in the interviews. The data collected has not been analyzed using a coded transcript or a format, but have been processed qualitatively. Therefore, the conclusion might need additional validation in the form of an evaluation of other experts in the field.

All in all, the validity of this researched has been maximized by the use of triangulation of data (Bryman, 2012). This means the usage of multiple data sources for case and cross-case analysis, such as documentation, internet sources, observations and interviews with both stakeholders and professionals. In this way, the qualitative nature of the research has been substantiated by as much different types of sources, for decreasing the dependency on context-specific aspects.

6.3 Recommendations

6.3.1 Scientific recommendations
This research has focused on the broad topic of adaptability in the long-term, yet could not cover everything. Therefore, recommendations on several subjects and problems have been given below for further research:

- It is known that lifespans are different per layer and per function, yet little research has been done on the quantification of such differences. More scientific evidence is needed on lifespan estimation in order for the practical field to make use of lifespan diversification in business cases.

- This research is based on perspectives of the long-term owners and stakeholders in the development process, as the long-term value of adaptability must become visible and workable for them. However, the perspective of the user and their perception towards adaptability and its added value might be interesting to research additionally. If users are willing to pay for additional adaptability, the long-term owners can be stimulated as well. More research on user preferences in relation to adaptability are therefore recommended.

- In this thesis it became clear that demountability is inherent to the adaptability of a building. Therefore, it is suggested to gather more knowledge and insights on the value of demountability and the interrelations of demountability and adaptability.

- This thesis has performed qualitative research and suggested to increase the lifespan of a financial model. This upfront approach should be analyzed after a considerable period to determine to what extent the assumptions have been realistic and valid. Further research could be conducted in a quantitative way, where the (long-term) business case has been analyzed in retrospect, to validate or complement the data available and perhaps provide additional factors.

- This study has only covered a specific type of real estate. It is interesting to look at other cases in different functions and typologies to determine the adaptive capacity and its financial benefits over time and to enrich the body of knowledge. A similar study with other and more cases that could eliminate context-related factors is therefore recommended.

6.3.2 Practical recommendations

Based on the outcomes of this graduation thesis, several recommendations for practice have been provided for a better implementation of adaptability. Note that there might be some overlap with the conditions mentioned in chapter 6 Synthesis.

- Do not wait for others, but explore yourself
  The complexity of the posed problem is high. There is still much information and knowledge lacking, which makes organizations reluctant to make steps towards a more circular economy. This thesis challenges all organizations to make efforts, albeit small efforts, and not wait for large breakthroughs out of the field, but to explore yourself.

- Join forces cross-disciplinary
  Try to avoid traditional division and competition, but rather opt for collaboration and transparency on information with parties that are also making attempts. This collaboration will help in solving the encountered problems and challenges by exchanging specialized knowledge to go to long-term value creation.

- Invest in data gathering and processing
  More research on alternative valuation methods and financing approaches are needed. Increase the database with experience-based data on transformation costs and reuse, as well as on residual value estimations and quantification of soft values to enable further development of a long-term financial model. Collaboration with organizations that are specialized in collecting and managing databases could be beneficial for the development of the financial model in practice.

- Consider the vital role of clients
  The role and influence of an owner or client in a project has been broadly covered in this thesis. It became clear that the their role is vital for the degree the adaptability adopted in a buildings because of several reasons.
    - The client sets the direction of the development strategy, ambitions, requirements and ownership structures.
    - The client has a more long-term perspective than the developer or suppliers, which leads to other focus points and perspective.
    - The client is the one investing in the real estate eventually, and is therefore the sensitive key between costs and benefits.

Early involvement of the investor or client in the (re)development process is therefore key to stimulate sustainable (financial) choices.

- Consider the accelerating role of the government
  The government should take an active role the transition towards more adaptable real estate by establishing legal conditions or requirements related to adaptability, demountability and the reuse of resources. Think of obligatory use of material passports or assessments tools and minimal scores on adaptability.

- Steer upfront instead of measure afterwards
  The approach towards adaptability should become more pro-active instead of reactive. Organizations should steer on adaptability just as on quality and time, and from the first phase on already.

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Appendices

Appendix A

Informed consent

For the interviewees in the Graduation Research of Bauke Brekelmans

I. Research information
II. Consent form – interviewee
III. Consent form - interviewer

I. Research information

First of all, I would like to thank you for participating in this research. My name is Bauke Brekelmans and I am currently a graduate student at the Delft University of Technology at the department of Management in the Built Environment (MBE). This interview is part of the graduation research; Adaptable Real Estate - The added value of adaptability in a long-term business case. Within this research the main goal is to explore how we can better include adaptability in the business case, so that its added value in the long term becomes better visible and workable. This interview will help in gathering experiences from practice to deliver a set of conditions for an improved adaptable business case. In the end it is hoped to stimulate the take-up of adaptability in practice.

Background information
The take-up of adaptability in new developments is not as high as is desirable from a social and environmental point of view. The main cause is that adaptability is thus far not motivating developers and investors financially, and current business models do not take the added value of adaptability into account. These models are created in a linear economy of take-make-dispose, and therefore it has difficulties with the implementation of a circular approach such as adaptability. This research strives to identify the main features that allows for adaptability in the future, as well as the main obstacles in practice, and how to better incorporate them in a financial model. The final product will be a set of conditions for an improved adaptable business case.

Research method
The final output to improve the business case is based on the following research parts:
(1) Literature research
(2) Case study complemented by interviews
(3) Exploration of a long-term business case

As demarcation this research focuses on tall buildings specifically, defined as having a height of 70 m or higher. The motivation for this choice is the amount of matter and raw materials embedded in tall buildings, which is of such a large extent that it is especially important to allocate new functions in these buildings, so to make them better adaptable. Yet the findings of this research will apply to all buildings.

The literature review elaborates on the adaptability features that a tall building could have to enhance the adaptability and flexibility in the future. This interview is part of the case study. The interview will serve as additional qualitative information to explore a long-term business case and to support the set of conditions. The gained information of this interview is also necessary to answer my sub-questions.

The interview will be a semi-structured interview. This means that questions are defined and send to the interviewee prior to the interview. During the interview, the interviewer can ask further questions that may arise as a response to the interviewee. At any time, when a question is unclear, the interviewee has the freedom to ask for further elaboration. Also, if the interviewee wishes to not answer a question due to any reason, this will be respected.

Data processing and confidentiality

In order to process the obtained information adequately, I would like to ask your consent to record this interview. The recording will be transcribed to consult information during the course of the research. The recording and results will be exclusively used for academic purposes and will not be disseminated to other parties. If requested only the mentor team of the TU Delft can get access. The data obtained and recordings can be consulted if requested. The recordings will be stored offline and destroyed after one year after publication of the research.

Personal information and data provided will be processed anonymously and remain confidential. Only the organization and function will be mentioned to assess the validity of the data obtained. Citations might be used in the reporting; if desired there is the option to check these citations before publication. In addition a transcript of the interview can be added to the appendix of the research, unless requested otherwise. I would kindly ask you to fill in the form on the following page; II. Informed Consent – Interviewee. This form meets the standards of the Human Research Ethics Committee assigned by Technical University of Delft.

Withdrawal

As a participant, it is possible to withdraw from cooperation in this research at any time. A reason for withdrawal is not necessary. You can also withdraw the permission you have given to use the data obtained up to 5 working days after the interview has been conducted. In that case, all obtained data will be destroyed.

Team

Interviewer

Bauke Brekelmans

Mentor team Delft University of Technology:

Ing. P. (Peter) de Jong
Dr. H.T. (Hilde) Remøy
Ir. T. (Taeke) Bouma

Mentor RE:BORN

Niel Slob

Contact details for further information

Bauke Brekelmans

II. Consent form - Interviewee

This informed consent form is addressed to participants of the graduation research of Bauke Brekelmans, in the form of an interview. Please tick the appropriate boxes below.

	Yes	No
Taking part in the research		
I have read and understood the research information, or it has been read to me. I have been able to ask questions about the research and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this research and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that, when participating in the research, the interview will be record-ed and transcribed. The recording will be destroyed after one year after publication of the research.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for the graduation thesis of Bauke Brekelmans and the corresponding presentations. This does not apply to in-formation that is stated as confidential.	☐	☐
I understand that personal information collected about me, such as my name, will be processed anonymously and will not be shared beyond the mentor team.	☐	☐
I understand and give permission to make use of quotations from the interview in the graduation thesis.	☐	☐
I agree that the transcript of the interview can be included as an appendix in the graduation thesis.	☐	☐
Future use and reuse of the information by others		
I give permission for the use of the information that I provide, which are partly based on the anonymized transcripts of this interview, to be archived in the online educational repository of TU Delft, so it can be used for future research and learning.	☐	☐

Signature

______________________	______________________	__________
Name of interviewee	Signature	Date

III. Consent form - Interviewer

Information sharing	**Yes**	**No**
I have shared the information sheet to the participant of the research and interview and, to the best of my ability, ensured that the participant understands to what they are freely consenting.	☐	☐

Signature

____________________	____________________	__________
Name of interviewer	Signature	Date

Appendix B

Interview protocol

For stakeholders of the case: the Lee Towers

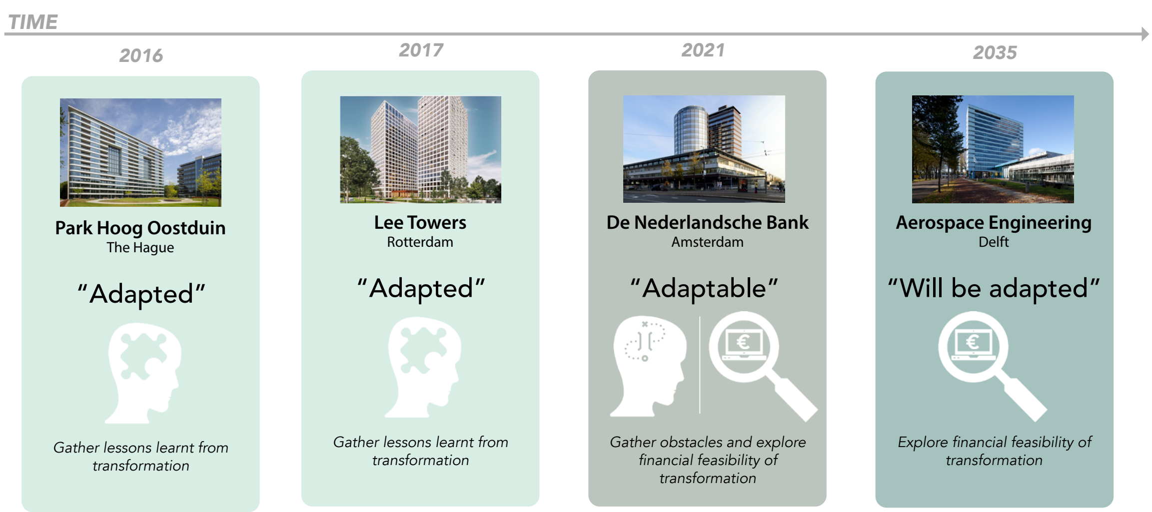
Datum: ______________________________
Organisatie: ______________________________
Functie: ______________________________

I. Introductie

Allereerst wil ik u nogmaals bedanken voor uw deelname aan dit interview. Voordat we beginnen wil u graag om toestemming vragen om dit interview op te nemen? [Start opnemen en start interview]

Dit interview zal de vorm aannemen van een semigestructureerd interview. Hierbij dienen de vragen als leidraad, maar kan er wellicht afgeweken worden van onderstaande vragen waar gewenst. Eventuele vervolgvragen die niet in deze vragenlijst staan kunnen gesteld worden als verdieping op een gegeven antwoord.

Een korte uitleg over het doel van de casestudie en de stakeholders die geïnterviewd worden.



II. Algemeen

1. Wat was jullie rol/functie binnen de transformatie van de Lee Towers?
   a. Wanneer zijn jullie betrokken geraakt bij dit project?
   b. Wat waren jullie belangrijkste verantwoordelijkheden binnen dit project?
   c. Wat waren de werkzaamheden waar jullie je mee bezig hielden?
2. Hebben jullie ervaring met transformatieprojecten?
   a. Zo ja, wat voor soort projecten/ervaring?
   b. Zo nee, hoe hebben jullie het ervaren?

III. Transformatie

1. Wat zijn vanuit jullie perspectief de belangrijkste voordelen om te transformeren i.p.v. sloop en nieuwbouw?
2. Zijn er vanuit jullie perspectief nadelen aan transformatie? Zo ja, welke?
3. Waar loop je bij een transformatie in het algemeen vaak tegenaan?
4. Hoe kijken jullie aan tegen de levensduur van een gebouw?
    a. Wat zou een optimale/realistische levensduur zijn voor een adaptabel gebouw?

IV. Lee Towers

1. Hoe is de structuur opgebouwd, en was deze flexibel genoeg om te transformeren naar woningen?
2. Hoe was de gevel opgebouwd, en was deze flexibel genoeg om te transformeren naar woningen?
3. Hoe waren de installaties opgebouwd, en waren deze demontabel?
4. Tegen welke aspecten zijn jullie aan gelopen in dit transformatie traject specifiek m.b.t. structuur, gevel, installaties en interieur?
    a. Hadden deze aspecten voorkomen kunnen worden in het oorspronkelijk ontwerp?
5. Is er in deze transformatie rekening gehouden met mogelijke andere functies in de toekomst?
6. Zijn er keuzes gemaakt in deze transformatie m.b.t. structuur, gevel, installaties en interieur om de flexibiliteit voor de toekomst te vergroten? Zo ja, welke?
7. Waar ligt de grootste inspanning vanuit jullie bij dit transformatieproject?
8. Bij welke ingrepen lagen de grootste kosten binnen deze transformatie?
9. Vinden jullie dit een succesvol transformatieproject?
    a. Zo ja, beschrijf waarom.
    b. Zo nee, welke aspecten hadden meer aandacht mogen krijgen?

V. Proces

1. Wat waren de belangrijkste rollen en partijen binnen dit project?
    a. Welke partij was jullie opdrachtgever en hoe verliep deze samenwerking?
    b. Hadden jullie procesmatig de vrijheid in keuzes maken? Of werden er veel randvoorwaarden gesteld?
2. Waar lag de focus op in dit project vanuit de opdrachtgevers; was dat sturen op geld, tijd, kwaliteit, duurzaamheid, etc?
3. Wat zijn de belangrijkste lessen uit dit project (wat had er beter gekund) wat jullie mee zouden nemen naar toekomstige projecten?

VI. Overig

1. Zijn er andere projecten geweest waar jullie bij betrokken waren en waar bepaalde aspecten naar boven kwamen die de flexibiliteit en adaptabiliteit van het gebouw verminderden?
    a. Wat waren deze aspecten die de adaptabiliteit verminderden?
    b. Hoe is hiermee omgegaan?
2. Hoe zien jullie de bouwsector in een circulaire economie voor jullie?
    a. Welke stappen zouden er vanuit jullie perspectief gezet moeten worden?

VII. Afsluitend

1. Hebben jullie nog vragen of opmerkingen over mijn onderzoek, het interview of iets anders dat gerelateerd is aan dit afstudeeronderzoek?
2. Kan ik een van jullie in de komende weken nog benaderen, mocht ik een antwoord op een cruciale vraag missen?
3. Zou ik overige documenten zoals plattegronden, maar eventueel ook bouwkosten omtrent dit project kunnen verkrijgen?

Appendix C

Excel calculations DNB

General information

GFA		8190	m2

Traditional

		Price /m2	
Construction	Building costs	€ 1.500	€ 12.285.000
	- Structure: linear load (structure and spaceplan partly combined), wet connections used leads to lower costs, but only downcycling is applicable for the future.		
	- Skin: Curtain wall		
	- Services: Central heating and cooling		
	- Space plan: Partly loadbearing, partly metalstud walls.		
Removal	Demoltion costs	€ 83	€ 680.000
Reconstruction	Building costs		
	- Structure	€ 439	€ 3.595.410
	- Material	*€ 272*	
	- Labour	*€ 71*	
	- Foundation	*€ 96*	
	- Structure	€ 315	€ 2.579.850
	- Material	*€ 236*	
	- Labour	*€ 79*	
	Total		€ 6.175.260
	Subtotal		**€ 19.140.260**
Environmental costs	MPG calculation environmental costs		€ 144.507
Residual value	Residual value at end of functional lifespan		€ -
	Total		**€ 19.284.767,00**

General information

	GFA	8190	m2

Circular

		Price /m2	
Construction	Building costs	€ 1.575	€ 12.899.250
	- Structure: Point load, column grid. Design for dissassembly leads to higher costs, but there is also a residual value potential (both with transformation and demounting and remounting).		
	- Skin: Curtain wall		
	- Services: Central heating and cooling		
	- Space plan: Metalstud walls.		
Removal	Harvesting costs	€ 220	€ 1.800.000
Reconstruction	Building costs		
	- Structure	€ 255	€ 2.088.450
	- Material	*€ -*	
	- Labour	*€ 71*	
	- Refurbishment	*€ 184*	
	- Skin	€ 247	€ 2.022.930
	- Material	*€ -*	
	- Labour	*€ 79*	
	*- Refurbishment**	*€ 118*	
	- Upgrade to BENG	*€ 50*	
	Total		€ 4.111.380
	Subtotal		**€ 18.810.630**
Environmental costs	MPG calculation environmental costs		€ -
Residual value	Residual value at end of functional lifespan		€ (6.836.423,30)
	Total		**€ 11.974.206,70**

Residual value

General information

GFA	8190	m2

Circular

	Weight in kg	*Material price per kg (2021)*	*Material price per kg (2052)*	Residual value
STRUCTURE				**€ 6.642.839**
Building costs 2022 indexed				€ 6.642.839
SKIN				**€ 193.584,00**
- Aluminum skin panels	14400	€ 2,03	€ 3,76	€ 54.144,00
- Bronze profile	14400	€ 4,25	€ 7,85	€ 113.040,00
- Glass elements	110000	€ -	€ 0,24	€ 26.400,00

TOTAL	**€ 6.836.423**

Sources

- Aluminum skin panels	London Metal Exchange, price date 30-4-2021
- Bronze profile	Metalimex, price date 4-5-2021
- Glass elements	Sustainability Victoria, September 2014, indexed to 2021