MBE GRADUATION THESIS

LAUREA MAGISTRALE

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Demolishing Buildings at the Right Time – How to determine the optimal lifecycle for demolition?

Developing a mathematical model which considers environmental, financial and social sustainability in order to determine when is the best timeframe to endeavor a new development.

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3.1 ABSTRACT

This thesis aims to develop a mathematical and financial approach that determines the optimal timeframe within a building's life cycle to demolish the existing building and replace it with a new development focusing on financial viability while accounting and acknowledging other sustainable aspects.

Furthermore, the thesis recognizes that in order to endeavor a re-development it is paramount to consider doing it in a Sustainable way, that is, analyzing not only the environmental impact, but also financial and social needs, thus the result must address these three components of sustainability. It will provide a framework, in which the financial impact is a support tool to make decisions that impact our built environment.

Initially, the thesis analyzes and presents the common trends regarding demolition decisions. Once these are captured it categorizes the literature according to environmental, social and financial approaches. Subsequently, it outlines how to construct a framework model from the financial standpoint of view, considering sustainability facets, and aggregates all necessary information for an assessment. Finally, a mathematical model is applied to a hypothetical case study which highlights the financial life-cycle cumulative costs and determining an optimal timeframe for demolition. The conclusion incorporates the remaining sustainability aspects for a sound decision.

This work is inspired by the fact that we must evolve as a society that embraces engineering and science, while finding a balance between endeavoring new developments and selectively preserving our cultural heritage accounting in both cases the 3 pillars of sustainability. Ultimately, the goal is to make objective decisions that positively influence our built environment and society in the long term.

3.2 ABSTRACT (ITALIAN)

Questa tesi mira a sviluppare un approccio matematico e finanziario che determini il lasso di tempo ottimale all'interno del ciclo di vita di un edificio per demolire l'edificio esistente e sostituirlo con un nuovo sviluppo incentrato sulla fattibilità finanziaria, tenendo conto e riconoscendo altri aspetti sostenibili.

Inoltre, la tesi riconosce che per intraprendere un percorso di riqualificazione è fondamentale considerare di farlo in modo sostenibile, ovvero analizzando non solo l'impatto ambientale, ma anche le esigenze finanziarie e sociali, quindi il risultato deve affrontare queste tre componenti della sostenibilità. Fornirà un quadro in cui l'impatto finanziario è uno strumento di supporto per prendere decisioni che hanno un impatto sul nostro ambiente costruito.

Inizialmente, la tesi analizza e presenta le tendenze comuni relative alle decisioni di demolizione. Una volta acquisite, classifica la letteratura in base ad approcci ambientali, sociali e finanziari. Successivamente, delinea come costruire un modello quadro dal punto di vista finanziario, considerando gli aspetti della sostenibilità, e aggrega tutte le informazioni necessarie per una valutazione. Infine, un modello matematico viene applicato a un caso di studio ipotetico che evidenzia i costi cumulativi del ciclo di vita finanziario e determina un lasso di tempo ottimale per la demolizione. La conclusione include i restanti aspetti di sostenibilità per una decisione valida.

Questo lavoro è ispirato dal fatto che dobbiamo evolverci come società che abbraccia ingegneria e scienza, trovando al tempo stesso un equilibrio tra la ricerca di nuovi sviluppi e la conservazione selettiva del nostro patrimonio culturale, che in entrambi i casi sono i 3 pilastri della sostenibilità. In definitiva, l'obiettivo è prendere decisioni obiettive che influenzino positivamente il nostro ambiente costruito e la società a lungo termine.

3.3 INTRODUCTION

How are we determining today when a building should be demolished? Is there any framework or systematic procedure to follow to take such a decision? And if so, which are the different impacts we are accounting for?

This paper stems from the hypothesis that nowadays, when taking decisions on whether to demolish or preserve a building for new developments, not all facets of such proposals are being considered, which ultimately leads to decisions being made in a biased manner. This leads, on one hand, to excessive demolition focused on profits, or contrarily derives in preserving significant and varied asset classes based upon cultural heritage rules.

The objective is to define a framework through which a mathematical model can be employed to objectively assess the financial standpoint of view of demolition, followed by accounting for other sustainable aspects such as the environmental and social.

For the literature review, an in-depth analysis was performed on over 50 papers, 2 books, and multiple articles. Among these, there were multiple direct and indirect sources that addressed similar touchpoints and conclusions. Finally, circa 30% were selected as the backbone of this thesis and encompass in a considerable measure today's main research on demolition Environmental, Social and Governance aspects. However, it is worth noting that backing up each of these papers exist a significant number of other sources that contribute indirectly to the present work.

In general, it is found that the majority of nowadays research is focused mainly on addressing the environmental impact of demolition, addressing embodied life-cycle carbon emissions, renovation focused on energy efficiency and its operative emissions and finally the environmental impact of demolition residue, as a matter of fact 70% of the material found addressed this topic.

Another considerable portion of research has focused on identifying the criteria for demolition and end of service life which overall aim to integrate different facets, however they do so on a high level. These criteria are used for the basis of decisions as we will later see. Finally, the remaining information is scattered through topics such as statistical information, deconstruction, and management of demolitions residue.

In virtue of the prior literature review, the thesis aims to combine in an initial mathematical model the environmental and financial impact, which would then finally be complemented by the criteria for demolition and end of service life who addresses the social aspect as well as other important topics. This will help take a next step to complement diverse papers out there that already address environmental and social aspects, however, sustainability also encompasses the financial dimension which must be also considered. Finally, a hypothetical case study on an office building in Europe is considered onto which model is applied in order to appreciate the results.

4. CHAPTER 2 – LITERATURE REVIEW

4.1 REAL ESTATE OVERVIEW & THESIS HYPOTHESIS

Before this thesis research topic is addressed, it is necessary to outline the different stages of a real estate asset life cycle. Generally speaking, real estate development is a loop that starts with an initial feasibility study which if successful leads onto a business case that aims at securing an investment for a development realization.

Once the financial resources are secured, the design stage of an asset is developed through different stages of detail until its construction can be undertaken depending on the type of project delivery method contract and the local permitting requirements. When the construction is finalized, its operative life begins and through its lifetime the asset must undergo multiple events of maintenance (Planned, preventive, corrective) in order to ensure its quality, functionality, and operational requirements.

The operative life can last through many years, and this timeframe differs significantly among real estate assets, factors such as: market use, asset class, ownership, maintenance, and multiple others contribute to these variations.

Upon reaching the end of the service life of a real estate asset, a decision must be made. The owner or asset manager has multiple options to decide from. Among these options the most common ones are selling, re-using through hard renovation or replacement and demolition, and it's in this exact milestone where the focus of this thesis is placed. So that this decision can be assessed through an ESG point of interest.

Figure 1 - Real Estate Asset life stages. Source: Own Work.

Initially, the scope envisioned resolving the question portrayed in the introduction, aimed solely looking at a given project from the financial point of view; however, it was noted afterwards that this approach would not yield satisfactory results among different actors due to its limitation of the different facets of ESG when demolition takes place.

The initial hypothesis proposed the following: Imagine any real estate asset which is of considerable age respect to technology advancements and whose cumulative costs can be portrayed on a graph during the course of its lifetime, in the first years we would see an important spike due to its development and construction, which once finalized, would yield constant cumulative costs year over year, assuming operative expenses, taxes and maintenance values as constant averages among other costs. This would represent the blue line on Figure 2.

Subsequently, let's include the same criteria for cumulative costs over a newly built asset, this would represent the green line. Furthermore, this new asset has had significant improvements in its engineering (architecture, structure, MEP, etc.), that would derive in first having an initial higher construction cost, and later an improvement in its operative efficiency and thus lower cost year over year.

Due to the slope reduction thanks to engineering advancements, the new building will eventually outperform the old one at some point in time where their cumulative costs will encounter due to the slope difference, and from this moment and on it will generate savings and benefits to their users.

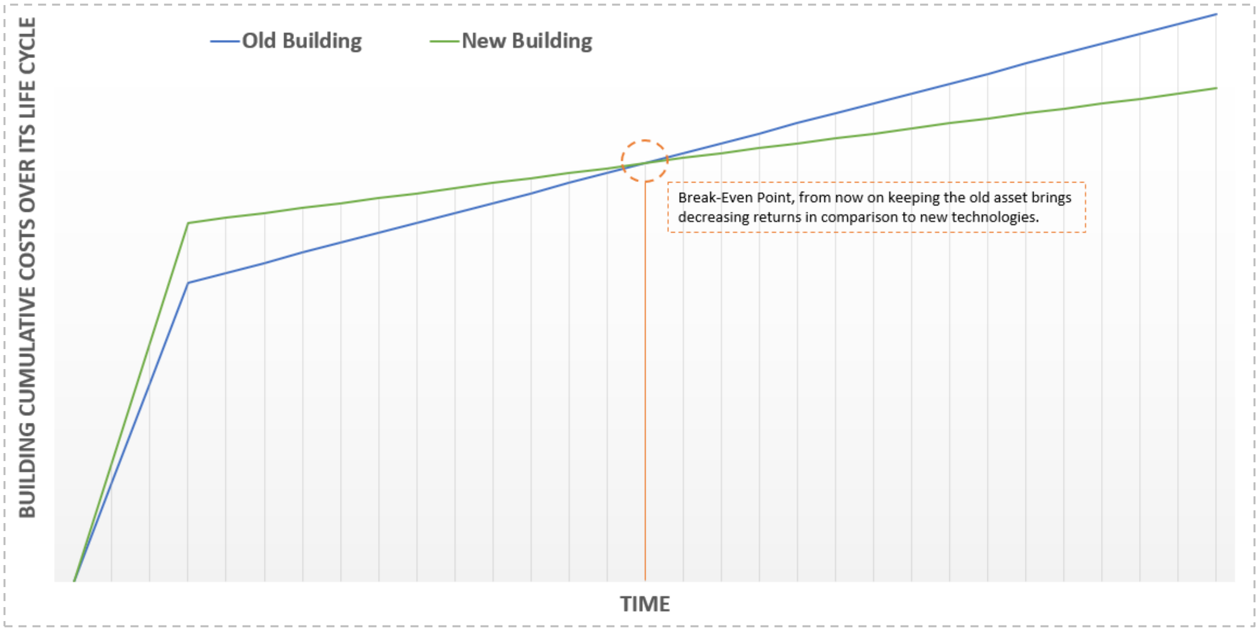


Figure 2 - Hypothesis of cumulative costs comparison among different age same class-built assets. Source: Own work.

This initial proposal is thought to aim at identifying when it would be the optimal time to consider a building demolition, based on engineering advancements which engender cost improvements on a long-term analysis. Moreover, it aimed not solely at breaking even financially, but also at justifying a recurring improvement to architectural and engineering advancements which benefit the society.

As it is going to be described later, this initial model its basic and thus in its current state presents simplifications from a financial approach, weaknesses addressing interconnected problems such as sustainability and some oversights.

Once this hypothesis was laid out, research was performed first on the rationale behind demolitions, and how we can portray a framework to address them considering social aspects. Second, how does environmental sustainability impact current real estate; And third, incorporating new quantitative measures into the model.

4.2 RATIONALE BEHIND DEMOLITIONS, FRAMEWORK AND SOCIAL ASPECTS

The literature addressing the determinants for a real estate asset end of life are scarce, for this reason (Thomsen & Flier, 2010) developed a conceptual scheme built upon different sources which aims to convey the motives of proprietors for demolition as follows:

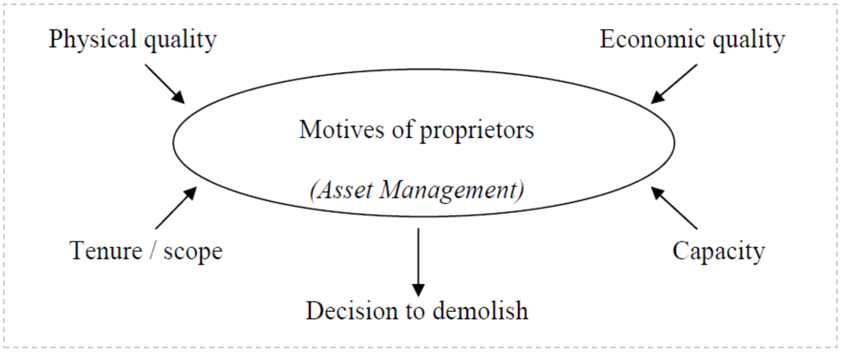


Figure 3 - Decision making about demolition, conceptual scheme. See (Thomsen & Flier, 2010)

In their research among different authors, these motives can be related to:

*"**Physical quality of dwellings**; dwellings can be demolished because the 'physical service life' has come to an end, either caused by:*

- *technical quality: the structural parts of dwellings are deteriorated and no longer keep their basic physical performances, and/or*
- *functional quality: the dwelling is no longer serving its purpose due to insufficient functional performance.*

*The **economic quality** of dwellings; dwellings can be demolished because the dwellings can no longer produce a positive cash flow and the 'real service life' has come to an end, either caused by*

- *the market potency: the effective demand for the dwellings has decreased, and/or*
- *the return potency: the returns are no longer covering the costs."*

He subsequently addresses proprietors' motives:

*"**Tenure or Scope** (…) The motives for demolition vary by tenure according to their interest and scope of the property owners. Motives of homeowners will be different from motives of social landlords or real estate managers because they have different primary objectives concerning their property.*

***Capacity** (…) The decision to demolish may have to do with the motives of housing managers but also with their capacities regarding capabilities and financial resources (…) professional nonprofit housing managers like housing associations have the capacity to organize and finance it, and (small) private landlords and owner occupiers do not. Therefore, the ability or the capacity of the proprietors has to be added to the scheme. Depending on the professionalization of the management, motives and capacities can be formalized in asset management or policy (Gruis & Nieboer, 2004)"*

Thus, according to the study we can synthesize the main reasons are in Asset functionality, Investment profitability, organizational motives, and financial leverage. Curiously enough, the same author published in 2011 a stronger conceptual framework which will be explained in Figure 4. Later on 2022 these same authors did a remarkable collaboration with multiple authors on an immense research project addressing more than 150 sources which cites both of his works (Thomsen, A.; Silva, A.; de Brito, J.; Straub, A.; Prieto, A.J.; Lacasse, M.A., 2022).

According to the (ISO 15686-1, 2011) standard, *“service life is defined as the period after installation during which a building or its components meets or exceeds the performance requirements”.* However, it is important to highlight that a building has significant number of components with diverse life expectancy values, whose renovation occur during its service life at different timeframes and thus it’s hard to specify an overall value. Furthermore, there are new methods such as the LCA (life-cycle analysis) which is a systematic process to evaluate the environmental impacts associated with all stages of a building's life, including material extraction, construction, use, and disposal. (ISO 15686-5:2017, 2017) However, these analyses are recurrently restricted upon strong assumptions, in this particular case they usually assume a service life between 30 to 50 years. (Grant, A.; Ries, R.; Kilbert, C., 2014)

Along with the Service life, there is a complementary term named ‘Obsolescence’ which is defined according to (ISO 15686-1, 2011) as the loss of the ability of a building element to perform satisfactorily due to changes in performance requirements. This is complemented with the aforementioned research project that states *“Various authors relate to a building’s obsolescence to their loss of performance or utility, which can be caused by their physical deterioration or due to economic and social motivations, technological or political changes, or even fluctuations in users’ needs.”* (Thomsen, A.; Silva, A.; de Brito, J.; Straub, A.; Prieto, A.J.; Lacasse, M.A., 2022)

After Thomsen & Van der Flier research on the decisions for demolition, they published a book and additional research addressing obsolescence which are (Thomsen, A.; Van der Flier, K., 2011) and (Thomsen & Van der Flier, 2011) where they managed to integrate different factors that have been discussed according to the figure below:

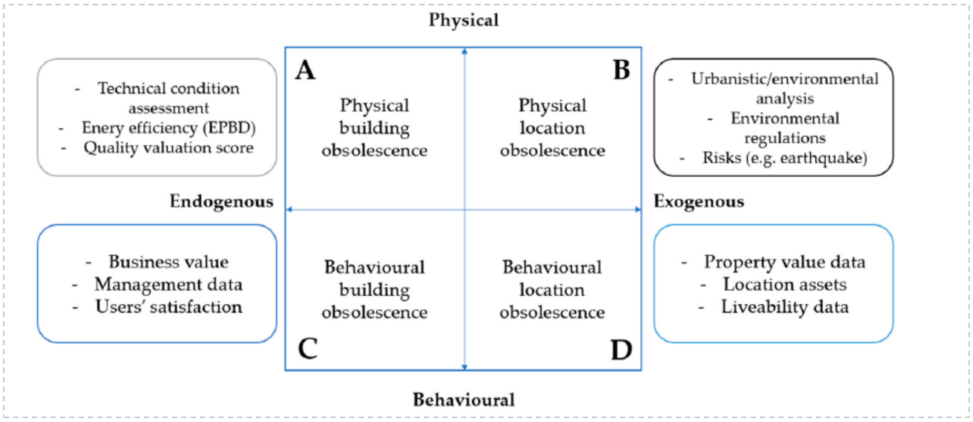


Figure 4 - Extended diagram of the two main cause-effect dimensions of obsolescence. Copyright 2022 Copyright Informa UK Limited; Copyright 2011 Copyright Thomsen, A. and Van der Flier, K.

“The analytical model proposed above is based on the premise that obsolescence occurs due to a sequence of complex, frequent, and interconnected cause-effect processes at different scales within and between the four quadrants of the model, leading to the depreciation of the building” (Thomsen, A.; Silva, A.; de Brito, J.; Straub, A.; Prieto, A.J.; Lacasse, M.A., 2022)

In addition, (Thomsen, A.; Silva, A.; de Brito, J.; Straub, A.; Prieto, A.J.; Lacasse, M.A., 2022) strengthens this analytical model, by presenting different triggers which engender the End of service life of a building. These are Physical degradation, functional and technological demands, legal requirements, social/community motivations and aesthetical or architectural trends. It addresses specially the concept of functional service life as an interconnection of the following:

- *"Functionality, related to the users' demands, considering the relation between the users' needs and the ability of the building to fulfill these needs or to perform to a given level of demand.*
- *Serviceability, which is related to the extent to which the building is appropriate or valuable in addressing users' requirements.*
- *Suitability, which is defined as a building's capability to support the functions or activities required by users"*

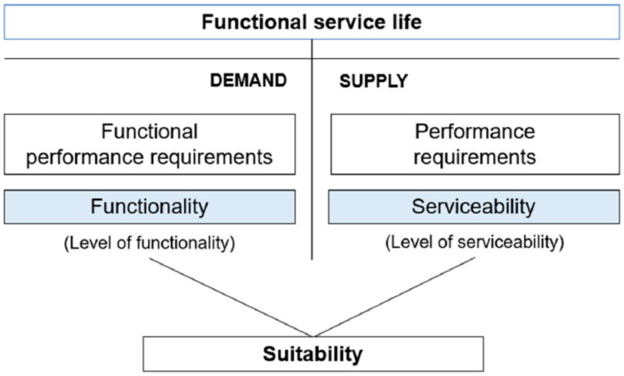


Figure 5 - Connection between functionality, serviceability, and suitability (Thomsen, A.; Silva, A.; de Brito, J.; Straub, A.; Prieto, A.J.; Lacasse, M.A., 2022)

While physical service life can be prolonged, the end of service life will occur anyway derived from users behavioral tendencies either by Aesthetic, legal, technological, functional, economic, or social reasons. In one way or another, these triggers can be fit upon the model presented before, but the important difference is that they aim at interconnecting the different reasons for obsolescence.

In virtue of the prior, thanks to the aforementioned authors and their work, a framework for the present thesis which conveys demolition determinants is proposed in Figure 6 - Reasons that engender demolition. Source:

It is paramount to note that the scope of the thesis does not envision addressing each of this reasons, but rather to provide a framework of why the necessity to demolish occurs and parallelly provide this as the basis of the mathematical model objective criteria such as physical, economical and Supply & Demand.

To reiterate the argument again, the aim is to determine when to demolish through a sustainable approach, that is environmentally, economically, and socially. In order to account for social sustainability, is in fact quite complex because it is interconnected among determinants. From the physical reasons is needed to ensure Physical building performance meets the user needs; In the supply & demand perspective to account for users purchasing power, functional and performance requirements; From the social reasons that such project is aligned to the culture of the society where it is aimed, and that the community understands its benefits.

Physical reasons: Envisions Physical building obsolescence, Physical Quality, degradation, and technical performance.

Economic Reasons: Include owner profitability, resource capacity, business value, organizational motives.

Supply & Demand: Are as per the definition above and are linked to functionality, serviceability, and suitability. User oriented.

Social Reasons: Cultural, community motivations, Collective perceptions.

Externalities: Risks, Regulations, Legal requirements, and others.

Figure 6 - Reasons that engender demolition. Source: Own work.

This first part has concluded by providing an overview of what to account for when such milestone occurs and the different facets on what to consider from the social part of sustainability.

4.3 ENVIRONMENTAL SUSTAINABILITY

In a first instance, the scope of the thesis only envisaged the development of a mathematical financial model to determine the demolition timeframe, and as research underwent it was captured that one of the most delicate and urgent topics regarding demolition is its impact on environmental sustainability, specifically on global warming. So even if the mathematical model was sound, without addressing the environmental aspect it would eventually receive pushback from its implementation, for this key concepts regarding environmental topics will be addressed albeit summarized in order to highlight what's in scope.

Real estate has a huge impact on the planets environment and its causes can be divided into two categories. The first category and most obvious is the impact that service utilities have on the environment, as the constant energy requirements for heating and cooling summed up through a buildings cumulative life cycle adds up significantly, in fact buildings incur in 25% of the European operational Greenhouse Gases (GHG) (Norton, B; Gillett, WB; Koninx, F, 2021).

On reference to the second category, and a more complicated topic, is the embodied GHG emissions which refer to all the greenhouse gas emissions accumulated from a real estate development throughout its supply chain until its construction is finalized, once completed it is said that the aggregate sum of all building component GHG emissions make up for the building embodied GHG emissions. The impact of the prior according to the UNEP is " *The construction industry is responsible for 40% of all anthropogenic CO2-related emissions and is one of the industries that contributes the most to global warming*" (UNEP, 2019), this impact is remarkable and according to (Norton, B; Gillett, WB; Koninx, F, 2021) "*The largest embodied emissions of a building are in foundations, floor slabs and structural components that contain steel and cement*"

In virtue of the prior, it is paramount to annotate that even though the initial one-time cost of constructing a building is high we must not overlook the recurrent cumulative GHG that the building incurs throughout its lifetime by means of renovations due to its physical obsolescence. Note that as per the previous source "embodied emissions from renovations can be up to 50% of those from new buildings." (Norton, B; Gillett, WB; Koninx, F, 2021) renovations also have embodied emissions.

Finally, the mentioned study, concludes that by implementing regulations and directives which aim at fostering renovation, it may be possible to barely surpass the 2 degrees carbon budget we have by 2050.

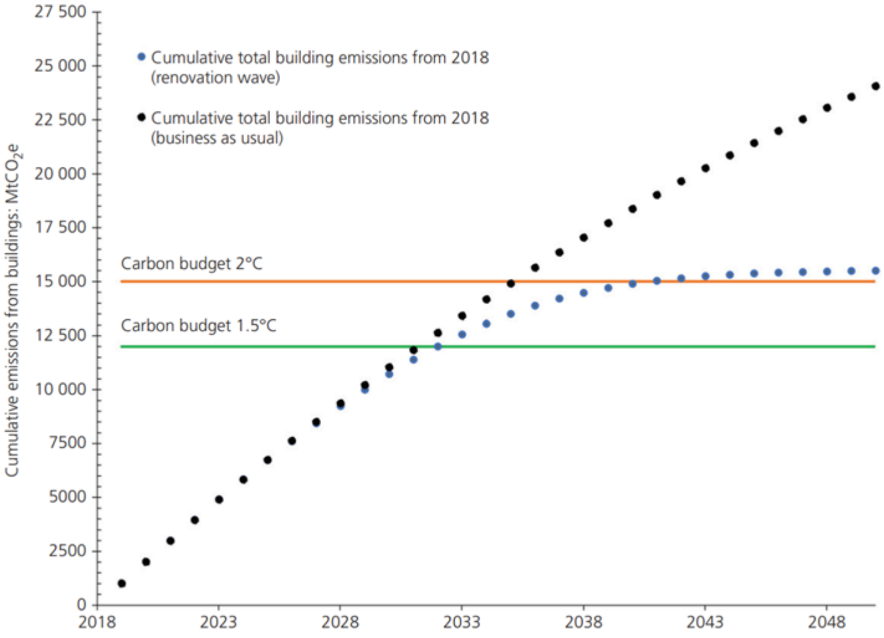


Figure 7 - Impact of a European renovation wave on the cumulative emissions from EU buildings. (Norton, B; Gillett, WB; Koninx, F, 2021)

The figure above is astounding, even if we start employing important efforts on renovation, we will still increase the earth's temperature due to GHG emissions by 2 degrees in 2040. One important aspect is that this proposal from the paper is a **reactive** one, that is, it engenders through the necessity to swiftly tackle emissions in a very short period of time to minimize the impact of society.

What is proposed in this paper aims for a **long-term strategy**, in which through careful planning we can assess ex-ante, during and ex-post the project the demolition criteria. As a matter of fact, this paper does not intend to replace renovations at all. If that were to happen even if the operative emissions were reduced drastically, it would have a massive impact on the global supply chain and embodied GHG emissions. It has to be carefully planned, assessed, and executed in a long-term perspective.

¿How all the previous data translate into the context of Europe? For this the European commission sourced a tailored report from Copenhagen economics which has key insights into the real estate market (Copenhagen Economics, 2021). The paper first presents an overview of the building stock in Europe and how it has been categorized according to their EPC labels, and then filters millions of buildings by their country of origin, identifying potential for renovations, and exposing their construction year.

But what are EPC labels? They are Energy Performance Certificates that are based on the energy cost per square meter which indirectly states a building energy efficiency. These labels range from G (least efficient) to A (most efficient); however this increases are not proportional, in fact they tend to represent logarithmic returns, in other words, the benefit from improving from an EPC label of G to F is much greater than improving from B to A. These labels are important to this thesis, because they can help narrow the target buildings upon which a demolition would engender significant environmental improvements from a cumulative GHG emissions perspective. Appreciate below the current state depicted in the paper:

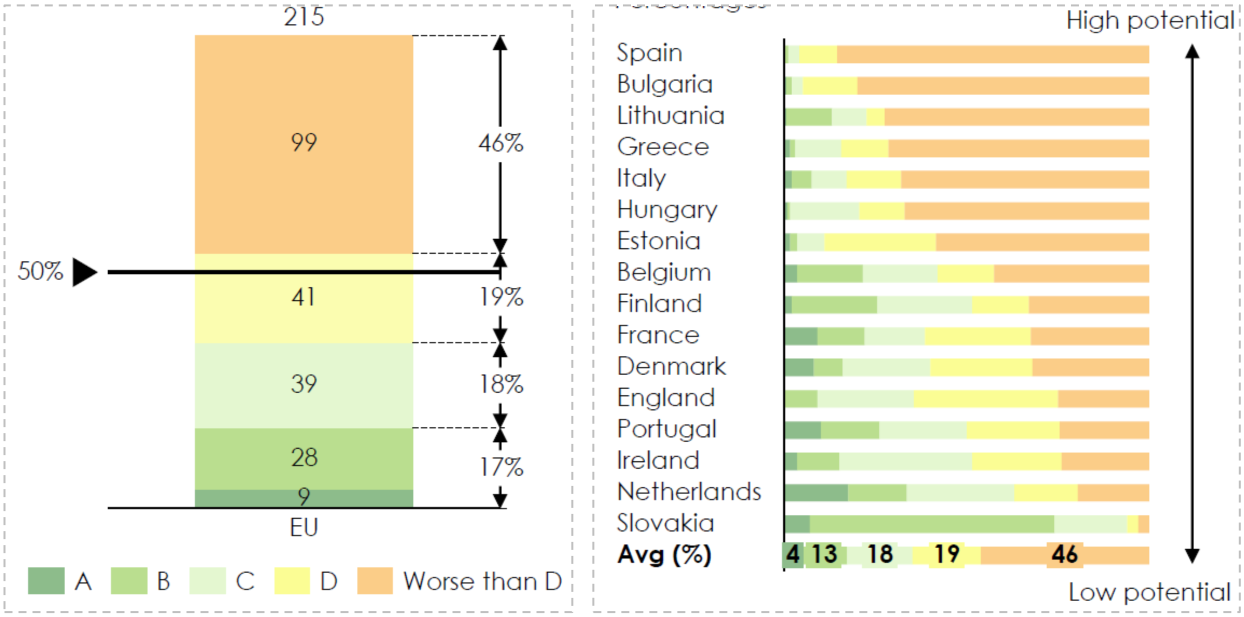
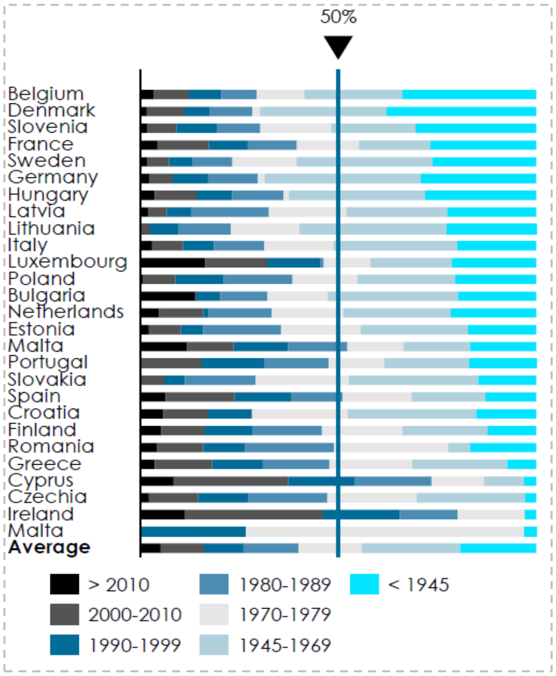


Figure 8 - (Left) Median EPC label of the EU building stock in millions of buildings. | (right) The EPC label % distribution among EU countries. Source: EU Building stock observatory (Europa.eu) & (Copenhagen Economics, 2021)

Notice that the median of EPC label distribution in EU is located in lower limit of category D, meaning that a considerable percentage of the EU building stock would benefit from increasing returns either by means of hard renovation or demolition. Moreover, on the figure on the right, we could narrow the countries where these modifications would engender more benefits. One thing this study does not account for is comparing this distribution in contrast to their energy consumption.



The paper also categorizes the current EU building stock by years of construction, which will later be of importance for the model.

As appreciated on the graph, circa 50% of buildings were built before 1979, in other words the current building stock already has over 50 years in its service life.

Furthermore, the Bank of Italy conducted a data analysis study. The research investigated the impact of the energy efficiency, assessed through the Energy Performance Certificate, on the value of residences at provincial level in Italy. The analysis of the data showed first of all that in Italy, based on Immobiliare.it data, only 10% of buildings with high energy class (A1-A4) are efficient, while 65% of buildings belong to classes F and G. (Michele Loberto; Alessandro Mistretta; Matteo Spuri, 2023)

Figure 9 - Residential buildings by construction year. EU Building stock observatory (Europa.eu) & (Copenhagen Economics, 2021)

The study also takes one step ahead and incorporates financial matters. Subsequently, it proceeds to indicate that even if there is potential to renovate an important part of stock, it must be noted that cost and benefits for renovations are not the same for all EPC labels and may derive in decreasing returns at higher energy performances. To conclude, it means that when endeavoring an energy renovation, the selected class improvement needs to be analyzed ex-ante to ensure adequate returns in the future and also achieving the efficiency required.

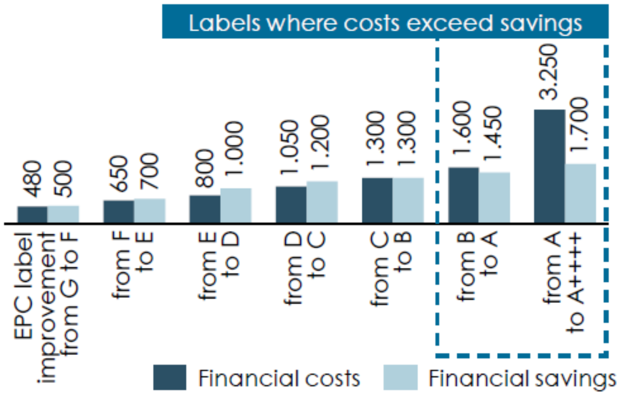


Figure 10 - Financial cost and savings of energy renovations per EPC label in the Netherlands. EU/unit/year (25year investment horizon OCC 6%) Source (Copenhagen Economics, 2021)

4.4 THESIS CORNERSTONES

So far, the presented literature offers in great measure the foundations for the framework from a theoretical point of view, and some information from a quantitative perspective. Among the literature researched, 2 special papers address specifically long-term solutions in a quantitative manner which address environmental sustainability.

4.4.1 First – Demolition vs. Recurrent Renovation recurrent embodied energy

The first paper which is "Building service life and its effect on the life cycle embodied energy of buildings" (Abdul, Rauf; Robert H., Crawford, 2014) performs a quantitative analysis on the Life cycle embodied energy of a building, accounting for Initial embodied energy and Recurrent embodied energy due to renovations, however it is important to note that the paper has 2 important limitations, the first is that it does not account for the recurrent embodied energy of operative use, and the second that it assumes the same level of technology for renovated performed on the asset.

The study performs multiple analysis of scenarios of replacement vs. renovation in a 150-year period for a house. On a first instance, the study proposes to calculate what would be the initial embodied energy of a house over 150 different scenarios. On the lower limit, the first scenario assumes that the house is demolished and rebuilt every year for 150 years; On the upper limit, it assumes that the houses is demolished and rebuilt every 150 years. Results are show as follows:

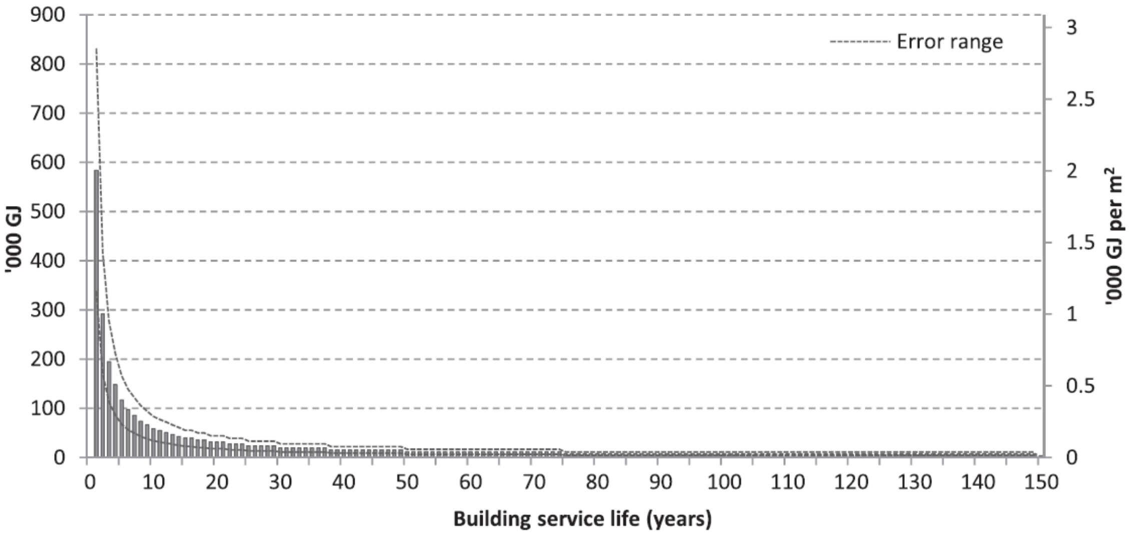


Figure 11 - Cumulative initial embodied energy of the case study house, by building service life over a period of 150 years. Embodied energy is depicted on the Y axis (Abdul, Rauf; Robert H., Crawford, 2014)

The result is clear, on the most extreme case which assumes demolishing and rebuilding every year the energy levels skyrocket (583,717 GJ), and as we look further into a long-term period, we can actually see how from an initial embodied energy point of view, these values stabilize. As per the paper :

"Life cycle embodied energy decreases at a significant rate as the service life of the house increases to 40 years, down to 22,518 G. It then continues to decrease, but at a much slower rate before trending upwards

again after a building service life of 105 years, due to an increasing demand for recurrent embodied energy. For a building service life of 150 years, the life cycle embodied energy was found to be 14,139 GJ"

In addition, the paper calculates separately the recurrent embodied energy due to renovations for each scenario listed in Figure 11, (i.e. house demolished every 20 years would still have renovations over its LC)

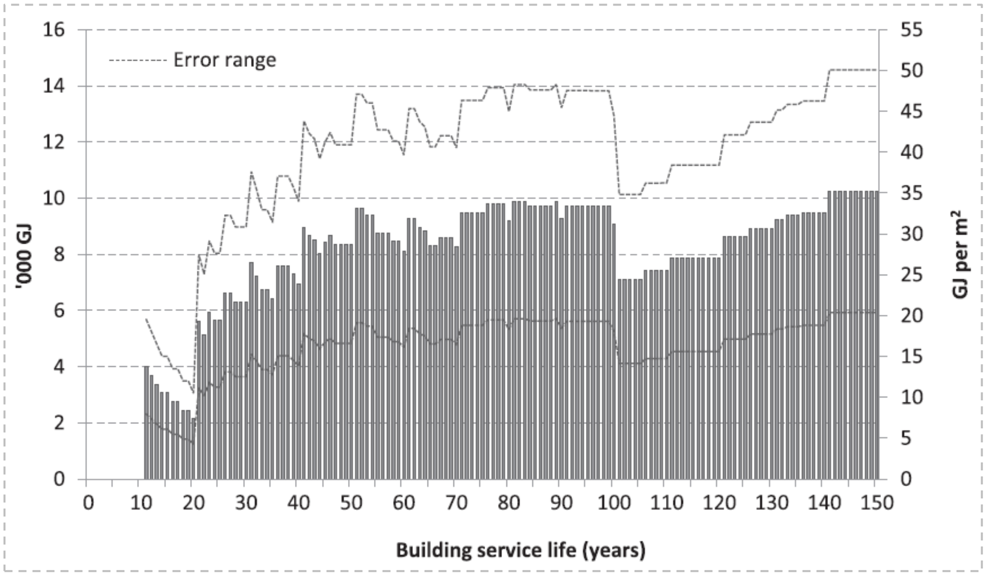


Figure 12 - Recurrent embodied energy of the case study, by building service life over a period of 150 years. Std. error circa 40% but a downward trend is evident. (Abdul, Rauf; Robert H., Crawford, 2014)

Briefly summarizing the graph, the first 10 years there's no necessity for renovations then, afterwards there starts to occur renovations as per the calculated performances of each material from a physical deterioration perspective. This finding is remarkable, as it shows that over a long-term period (circa 50 years), renovations result in constant impact of recurrent embodied energy, reaching logarithmic returns. To synthetize, the paper does the integration of both results:

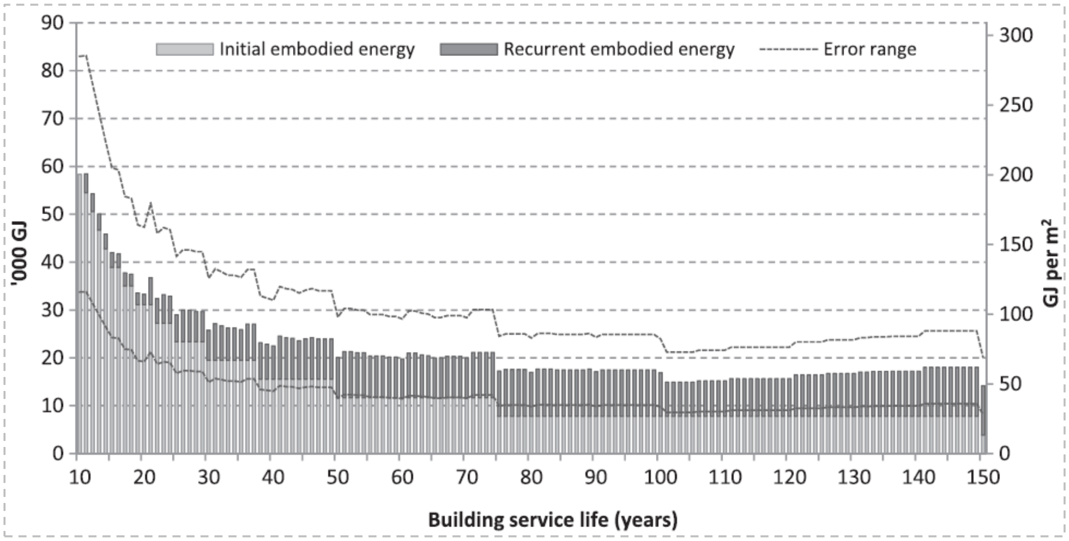


Figure 13 - Life cycle embodied energy of the case study house, building service life over a period of 150 years. Std error circa 40%, downwards trend is evident. (Abdul, Rauf; Robert H., Crawford, 2014)

The trend is definitive, over the course of 150 years in the scenarios of demolition + renovation, the energy values stabilize around the 50th-75th year, with a minimal difference in comparison to the years 140-150. Figure 13 is one of the cornerstones for this thesis, as it demonstrates that looking assets in a long-term perspective eventually lead to constant impact on energy values and not increasing ones, independent if the solution is whether reconstruction or renovation.

It is key to bear in mind that these results are based upon a specific real estate asset class typology, which in the case study is a single-story detached home, with a combination of concrete foundations, brick partitions and timber as its main structure.

This engenders the first limitation to this thesis, which is that the model from an environmental sustainability perspective is heavily dependent on the real estate asset class and the materials that it is built with. As an example, we could expect that from a building made entirely of concrete the constant trend of energy values will become constant in a longer timeframe, thus signaling a longer period necessary so that its demolition doesn't bring increasing impact on energy values.

4.4.2 Second – Demolition embodied energy vs. recurrent operative GHG emissions

The second cornerstone is perfectly described in the paper "Renovate or replace? Consequential replacement LCA framework for buildings (Huuhka, S.; Moisio, M.;Salmio, E.; Köliö, A.;Lahdensivu, J., 2023) which performs a Life Cycle Assessment from a carbon emissions point of view, comparing state of the art buildings, versus new construction and subsequently contrasting among them materials impact in construction between concrete and wooden solutions.

In order to analyze a building embodied energy in addition to its recurrent operative GHG emissions, the paper proposes a theoretical case, which in a fascinatingly it was found later on the research that it resembles the thesis hypothesis Figure 2 in Figure 14. In this theoretical case, instead of cumulative costs, the graph measures the GHG emissions, the initial spike refers to the construction of the asset (embodied emissions), and later down the line it estimates that such efficiencies break-even on a 30-year period.

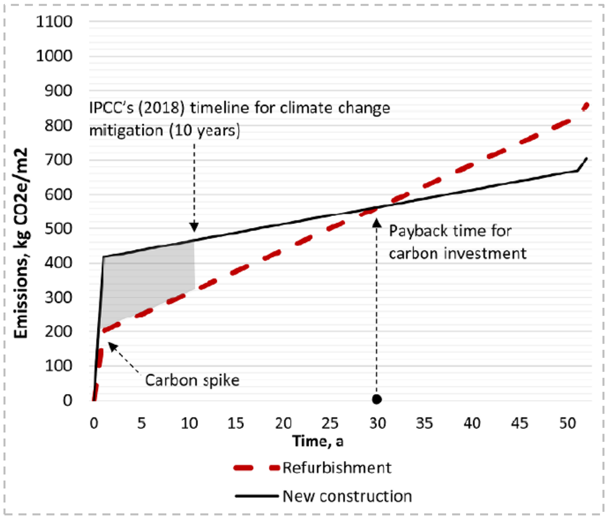


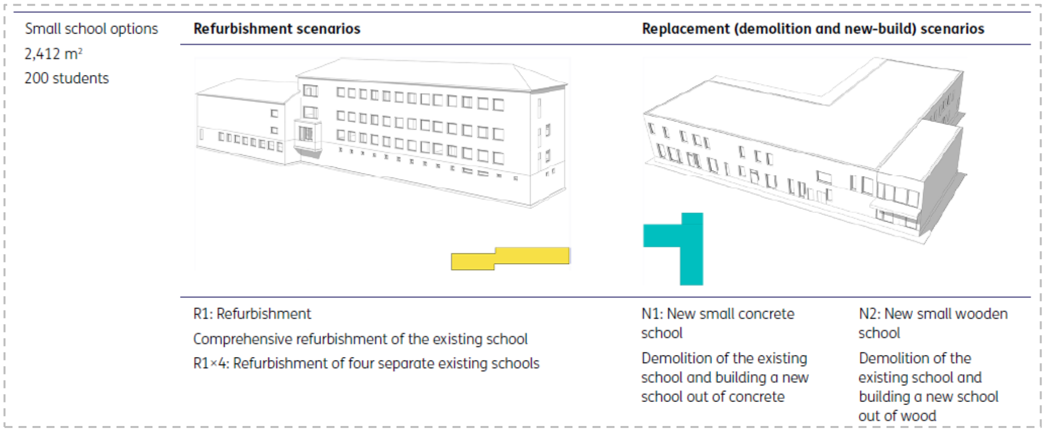
Figure 14 - Principle of CO2 accumulation for refurbished and new buildings, and some concepts. (Huuhka, S.; Moisio, M.;Salmio, E.; Köliö, A.;Lahdensivu, J., 2023)

Subsequently, after an extensive literature review in the paper on LCA calculation methods and background, they introduce the case study which aims at quantifying and analyzing their research and theoretical case. (For thesis scope purposes not all case studies were presented). Case study is as follows:

"The building used in the case studies for demonstrating the refurbishment scenarios is the Heterniitty school located in Helsinki, Finland (Figure 3). It represents a typical school building from the 1950s, with four floors, a narrow and long shape, load-bearing structures of brick, and plastered facades. The aim was to select a building to represent a cohort of buildings that are increasingly under the threat of demolition. To give the study's results relevance towards the larger stock of 1950s school buildings, any atypical structures that occurred in the building were exchanged into more typically occurring structures." . (Huuhka, S.; Moisio, M.;Salmio, E.; Köliö, A.;Lahdensivu, J., 2023)

Figure 15 - The case study school. "Heterniitty school" Source: City of Helsinki media bank (Lindén)

The paper then proposes to do the analysis over three different scenarios. The first one, named as R1 would involve a significant refurbishment of the building; The second (N1), would involve demolishing it and replacing it with a new concrete school; And the third (N2), proposes the demolition of the school but replacing it with a Cross-laminated timber solution. Finally, O1 refers to the school in its current state.



Small school options 2,412 m^2 200 students	**Refurbishment scenarios**	**Replacement (demolition and new-build) scenarios**	
	R1: Refurbishment Comprehensive refurbishment of the existing school R1×4: Refurbishment of four separate existing schools	N1: New small concrete school Demolition of the existing school and building a new school out of concrete	N2: New small wooden school Demolition of the existing school and building a new school out of wood

Table 1 - Heterniitty school analysis scenarios and volumetric view. R1 on the left and N1+N2 on the right. Note: area stays constant. Source: (Huuhka, S.; Moisio, M.;Salmio, E.; Köliö, A.;Lahdensivu, J., 2023)

After the performed analysis, the paper shows the results of each scenario energy consumption in Figure 16. As expected, the as-is case represents the worst-case scenario, followed by an improvement of 8% in the refurbished case, 40% in N1 and 35% in N2. Note these percentages also account for electricity.

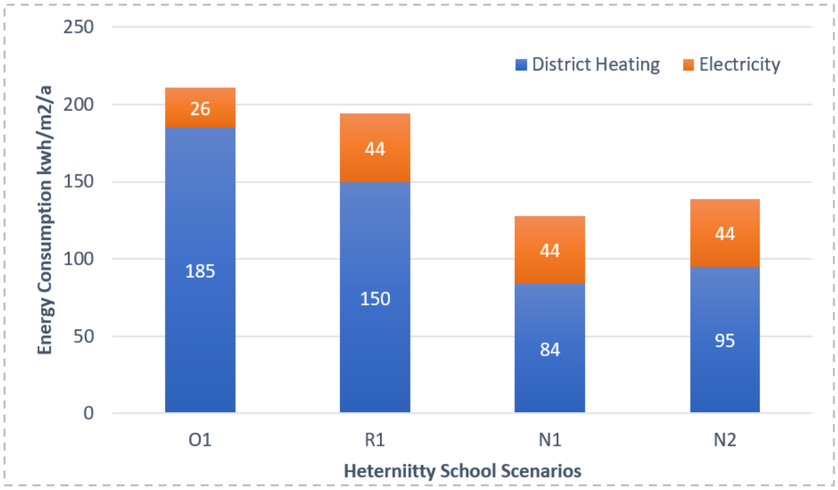
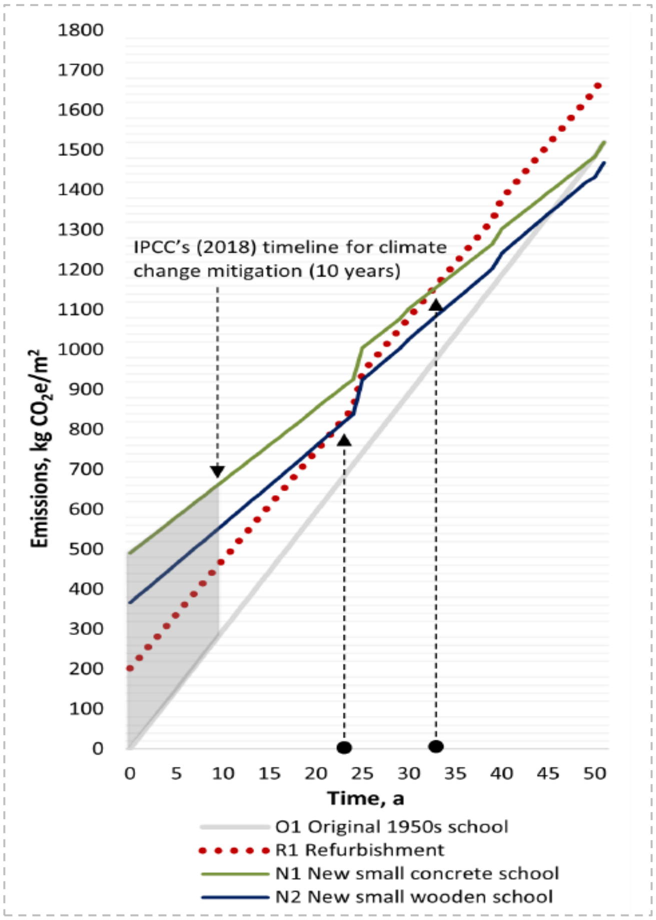


Figure 16 - Energy simulation results. Adapted from Source: (Huuhka, S.; Moisio, M.;Salmio, E.; Köliö, A.;Lahdensivu, J., 2023)



Thereafter, the paper presents the cumulative emissions for the case study for each scenario in Figure 17. This figure is in contrast with the original paper, since it doesn't account for energy decarbonization in the system, that's why it takes a linear shape. It has been included in this paper in its modified version because the objective is to analyze endogenous factors to the project and not exogenous ones, thus it derives in a limitation to the present thesis in accounting for each country policies to improve energy performance in their system.

Analyzing Figure 17 it starts with the emission spike for each case as a given, thus the initial part as per Figure 14 cannot be seen. Next, we can see that by year ≈22 the break-even point would be reached for the wooden building and that by year ≈ 33 for the concrete one when comparing against refurbishment, however our aim is to compare against the status quo, hence the break-even point would be reached by year ≈ 45 for the wooden building and by year ≈ 55 by the concrete building.

Figure 17 – Emissions accumulation for all scenarios when no decarbonization is assumed for energy production. Compare to the paper's Figure 6. Source: Supplemental data by (Huuhka, S.; Moisio, M.;Salmio, E.; Köliö, A.;Lahdensivu, J., 2023) Special thanks to Satu for providing me the supplemental information.

These results are exceptional, mainly due to the fact that multiple sources from the citations and sources within their papers tend to estimate the range of service life of buildings approximately between 30 and 50 years. This is not to generate confusion, the graph numbers do not dictate an end of service life, they simple dictate at which point the operative returns of a new construction would surpass current construction, thus making demolition sustainable in the long-term view combined with refurbishments.

As additional caveats, firstly the refurbishment performed on this case study does not indicate the improvement in regards to EPC labels which would be an interesting addition, albeit this doesn't impact the result against the status quo; Second, this is performed on a specific asset class with varied characteristics, nevertheless it is noteworthy that it is incorporated the inclusion of a more sustainable material thus demonstrating an even earlier break-point.; Third, this does not account for recurrent embodied emissions due to renovations in O1 and R1, in fact if it were to be included as in the previous case study, the gap between the wooden new construction would significantly widen against concrete.

Summarizing, so far, the general determinants for demolition have been presented along with the social aspects they convey, furthermore a review for environmental sustainability was presented and with these last 2 case studies the quantitative framework for the model baseline has been established.

4.5 FINANCIAL FACET

Having already established the literature review on the sustainability aspects for environmental impact and social needs, it is thus necessary to briefly review the financial facet, since it will be addressed in detail during the methodology review.

Overall, there's a significant portion of literature that addresses that for the most part when a demolition decision is taken, it is most likely driven by profits and most of the time ignores the different aspects of sustainability and social impact.

It can be said bluntly that the value of a building that has no demand or users is equal to 0. Simply put, an assets underlying value is directly linked to its capacity to meet market needs and requirements. When an asset economic performance is not expected or there is a greater potential opportunity, this engenders among many choices, the possibility concerning a demolition.

The typical analysis involves determining the required investment needed in order to reach either the expected economic performance or securing the opportunity and additionally, adding the cost of replacement. Once the figure is sound, a Discounted Cash Flow (DCF) is employed, which aims at forecasting future incomes that the new investment would engender and subtracting the related Investment, Capital and Operative expenditures and taxes. This operation is performed for a given timeframe where each time period yields a unique net cash flow.

Subsequently, these net cashflows are either subject to the Net Present Value method (NPV) or the Internal rate of return of the investment (IRR) which are the most typical in the industry. For the NPV, an opportunity cost of capital is established, and it is applied onto each net cash flow per time period with the aim of obtaining the net present value of the investment over the envisioned timeframe, if such value is greater than 0, the investment is sound. For the IRR, the goal is to determine the discount rate that sets the NPV of the investment's cash flows to zero. This rate indicates the project's break-even return. If the IRR exceeds the opportunity cost of capital, the investment is deemed sound. If it falls short, the investment should be reconsidered.

Along with these methodologies analysts usually employ other supporting techniques such as the payback period, profitability index, return of investment among others as additional guidance to take the decision.

This is the typical process from the financial point of view that derives to whether the demolition of an asset is feasible or not. As it can be grasped, currently it does not account for environmental or social aspects, it is purely financial driven on profits. While in some cases organizational motives behold social or environmental benefits this is not the common trend, nor it is considered in the analysis.

Furthermore, this financial analysis only considers the status quo and measures the investment costs against future incomes. Thus, it does not incorporate ex-ante characteristics of the asset during its life cycle from a financial point of view, it is not a methodology that envisions an end-to-end approach.

4.6 SPECIAL MENTIONS

Below are some papers that while were not part of the backbone of the thesis, present interesting topics that could be further discussed through additional works and which would ultimately be linked to an End-to-End process when endeavoring asset demolition.

There’s one important limitation to the current thesis, and that is that it does not address the how. In other words, if a demolition decision is sound from a sustainable point of view ¿How are we to perform such demolition so that it has the less impact? ¿What is the best way to do it?

Fortunately, this is a topic that has been under the spotlight for some years and new techniques are being proposed to minimize the impact of demolition. One example of this is EPA (United states environmental protection agency) which has incorporated Sustainable Management of Construction and Demolition Materials for these processes. One of the most remarkable is Deconstruction “Deconstruction is the process of carefully dismantling buildings to salvage components for reuse and recycling. Deconstruction can be applied on a number of levels to salvage usable materials and significantly cut waste.” (EPA, 2024)

Furthermore, in the UK reclamation audits are gaining traction, as a matter of fact there’s an important ongoing project at standardizing the approach at how demolition is performed, the book that envisions this project is named “A guide for identifying the reuse potential of construction products” and defines a reclamation audit as follows:

“A reclamation audit is an operation carried out in buildings scheduled for partial or total demolition. It aims at identifying the building materials and products presenting a high reuse potential. This audit results in a ‘reclamation inventory’, listing the identified reusable building elements. The resulting inventories present information on the materials' and products' characteristics such as dimensions, quantities, conditions, environmental impact, technical characteristics, disassembly recommendations, etc” (Morgane Deweerdt (BBRI); Marilyn Mertens (Brussels Environmnent), 2020)

It is seen that the approaches at the how of the demolition process are everyday more significant, and these endeavors paired with the present model will shape the futures end to end framework.

Another important mention is analysis that have been carried out by introducing statistical methods and deconstruction such as is the case of Decision-making analysis for Pittsburgh's deconstruction pilot using AHP and GIS (Zhang, Z.;Lee, J. D., 2023) where through a thorough analysis it as determined which was the best spot in the city to deconstruct.

Regarding statistical approaches, another paper aiming to define through big data sets the expected lifespan of buildings is Lifespan prediction of existing building typologies (Andersen & Negendahl, 2022), the data gathered is significant and might lead to some conclusions of past decisions, and the resulting model is interesting however it addresses demolition from a statistical point of view.

Last but not least, is understanding the structural design criteria of the assets. The design codes vary on a country basis and hold varying parameters and requirements; however, one thing holds true, each design code sets upfront what is the expected building service life, this value usually roams around the 50-year threshold and upon reaching that threshold structural components of the building theoretically start a degrading process and no longer perform at a 100% of their design values.

This would later imply hard concrete renovations that also have not been accounted for, in fact, due to evolution and technical regulations about 60% of existing buildings in Italy do not meet current seismic standards (ISTAT, 2011), even just doing energy renovations do not account for the risk of a disaster, in which case sustainable demolition would ensure social benefits to the government if it were to occur.

5. CHAPTER 3 – METHODOLOGY

In this chapter we will extract key information from the literature review that will serve as the basis for the model's foundations. Initially we will start mathematically from a financial point of interest, gathering the necessary data to approach the hypothesis proposal. Then the results will be adjusted/restricted by the findings related to the environmental impact and finally a social interpretation framework.

5.1 CASE STUDIES ASSUMPTIONS

In this section the cases for the model inputs will be described. In general, the model assumes 2 types of building, the first one is the baseline and will be treated as the old building (As-is situation) and the new building is the proposal (to-be situation) if it were to be replaced.

For pragmatic reasons, the case study and data in reference to be included in the model refer to the city of Milan in Italy, for a medium end residential asset class multi-family attached. The case study envisions a building of 1.000 m² of construction area with 75% or 750 m² of sellable area.

Both case studies are assumed to be owned by a single individual or firm which rents out the spaces to tenants and that given a long-term ownership of the asset they would like to evaluate if reconstructing it with the exact same characteristics (area, use and height) but with different materials, technology and engineering design it would eventually yield profits, without accounting for price increases in rent charged.

This assumption is key because it is relatively easy to make a replacement project feasible by either increasing its area, changing its use for more profits or simply increasing substantially the prices. It has also been a subject of diverse studies and discussions (which won't be addressed in this thesis) that demolition for new developments has a negative impact on its surroundings due to gentrification, thus the objective is to analyze what would be the result without a price increase. In summary, the objective aims at accumulating cost savings over time that generate a break-even point to the overall building cumulative costs during its life cycle as laid out in the hypothesis.

5.1.1 Old Building Considerations

The old building is assumed to be built in the present, however with the technology, engineering and materials which were employed in 1970, in other words, costs as of today but with the performance of the past. This specific time period was chosen because as per Figure 9 the average age of building stock lie in this period, along with the fact they do not compare in performance to a new build. Furthermore, prices of 1970, although feasible to grasp, were not considered because of the high volatility inflation and Construction prices indexes suffered due to historical events and also the conversion from Lira to Euro.

5.1.2 New Building Considerations

The new building is more straightforward, as mentioned above it will hold the same characteristics for area, use, height and rent prices as the old one, however its values assume a materials, technology and engineering performance as of today; Regarding its costs, these will be directly referenced to when the decision for demolition of the old one is taken from time t=0, because of the needs to account for inflation, additionally a surplus of initial investment costs will be considered to account for usage of best technologies, designs and materials available.

On farther chapters we will see that these assumptions, albeit peculiar hold true for any time period with the correct costs, given that an analysis of the different variables is performed for each project.

5.2 A BRIEF COST OVERVIEW

To develop the hypothesis model, we need to understand how we can summarize a buildings end to end lifecycle P&L (Profits & Losses), where losses are often referred to as LCC (Life cycle cost) summarized as:

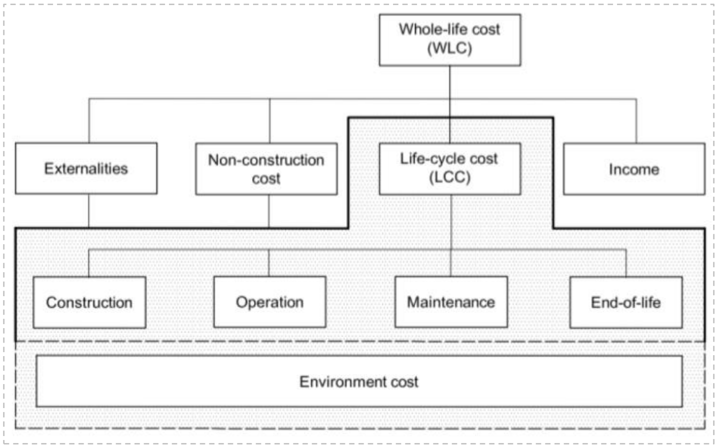


Figure 18 - Buildings LCC Chart (ISO 15686-5, 2008)

From another perspective, we can also view these costs throughout its service life as below:

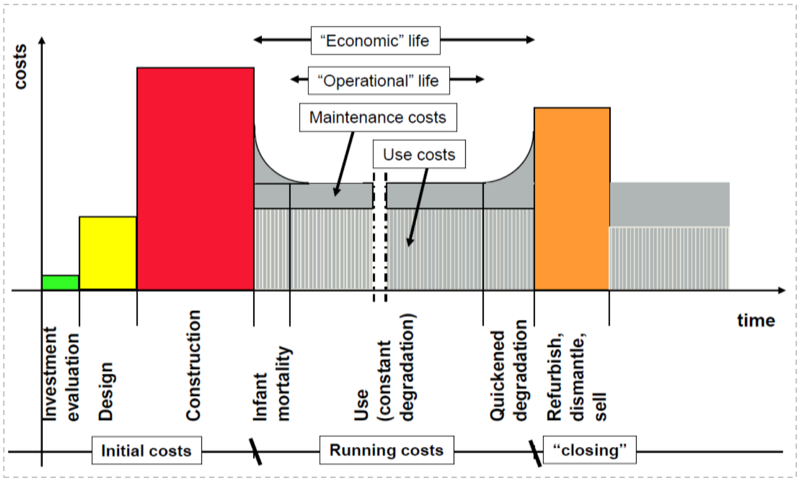


Figure 19 - Buildings LCC over time (Sonia Lupica Spagnolo, 2023)

A buildings LCC starts with the investment evaluation and design which are usually treated as sunk costs and are estimated through an approximation of the total construction costs. The construction costs are determined by the asset class envisioned to build, its architectural complexity, location, economic environment and the land value. Once the real estate asset is built, it undergoes constant CAPEX (capital expenditures) and OPEX (Operational expenditures) for the duration of its service life, and thus by looking at the cumulative cost (LCC) over time until its end of life, its operation and maintenance cumulative cost far surpass the initial investment. From now on the costs displayed above will be detailed on the same order presented.

5.3 ASSET LIFE CYCLE DURATION

There are diverse discussions into this topic, how to determine the duration of the asset's life cycle? In fact, knowing the exact number of years an asset will last is uncertain, this is where one of the thesis cornerstones will enter, to be precise in 4.4.1. Here one of the conclusions is that from an energy point of view, an asset reaches a constant state and with low volatility upon the 100-year threshold, for this reason for the present model we will adopt the same timeframe of 150 years.

The assumption to replicate this timeframe is that the same results hold true for the financial point of view with some variations, moreover, the model proposed could be even easily extrapolated for longer time periods if needed, although conclusions will prove this unnecessary.

Since this timeframe is significant, we must account for the inflation over the years, one assumption is that this will be held constant, albeit in reality it is quite volatile and heavily dependent on the economic environment. An approximate value of 2.5% is used, this value comes from averaging Italy's inflation rate from 1992 until the present. This specific timeframe was chosen because prior values had significant volatility and after said year, they have remained stable except for the last 2 years peak which is already recovering. A contract indexation of 100% is applied to the inflation rent, this is an assumption and may vary depending on the landlord/tenant agreement.

5.4 CONSTRUCTION, DESIGN AND INVESTMENT COSTS

The construction costs are heavily project specific, that is, even with approximations these vary significantly under the constraints explained before. To obtain the construction cost the ISTAT database for construction prices index was analyzed from the year 2000 throughout 2023, it is evident that due to recent economic events costs have seen a significant increase in the last 2 years. This construction index was paired with a database provided by the thesis supervisor which gave the base price of circa 1.600 EU/m² for the year 2015 (Genio Civile, 2015). The construction price is further linked up with the selling price of 3.200 for the same year whose estimates are based on IDEALISTA database.

Land cost is also project specific; however, it is common in the real estate industry to estimate it as a percentage of the total project investment, these ranges vary depending on organizational thresholds for the sake of simplicity a value of 15% has been chosen. The same is applicable to design costs, although their impact is minimal since their percentages are low and for this case an assumption of 5.0% was chosen.

Finally, it is known that construction costs take the shape of an S-curve, however since a long-term timeframe is being considered this has been simplified as at t=0 → land cost, t=1 → 1/3 construction cost and t=2 → 2/3 construction cost. Summary is as follows:

• Construction Cost:	2.000	EU/m²	(Doesn't include land)
• Selling Price:	4.000	EU/m²	
• Cap Rate:	7.5%		(Industry rate for non-prime locations, assumed)
• Rent:	25	EU/mo./m²	(Cap rate applied)
• Inflation:	2.5%		(Average 1992 – Present)
• Contract Indexation	100%		(Assumed and for simplicity)
• Land Cost	15%		(as a % of construction cost)
• Design Cost	5.0%		(as a % of construction cost)

Initial Investment	100%	(80% Construction, 15% Land, 5% design)

Adjusting these values to the case study we would have the following:

Construction Cost:	2.000.000	EU	
Selling Price:	4.000.000	EU	
Rentable area:	750	m²	(Old buildings have 75% sellable area)
Rent:	225.000	EU/year	
Land Cost	300.000	EU	
Design Cost	100.000	EU	
Initial Investment	2.400.000	EU	

5.5 OPERATIONAL LIFE COSTS

These costs encompass all expenditure the asset will require throughout the timeframe to operate such as utilities, administration, maintenance, insurance, taxes, renovations and other. Among these, there are some which are constant over time (that is, they're in relation to the asset type, price or revenues) and others which are non-linear and are dependent upon certain conditions. In the linear spectrum for this model, we can find utilities, administration, taxes and other costs.

- Utilities: A buildings services performance, assuming adequate maintenance of its components can be assumed constant over time, for example, a building with class energy G in 2024 was the same class energy when it was originally built.
- Administration: This value is market specific, and has little variance, is strictly connected to a buildings area, revenues and number of tenants. If the building remains the same in area, capacity and sources of revenue this value should be constant over time. For a residential building of the proposed area, it can be assumed and estimated around 1.5% of its yearly revenues.
- Taxes: These are not constant over time, however since these are externalities upon which we have no control are assumed constant. For a residential building of the proposed area, it can be assumed and estimated around 2.0% of its yearly revenues.
- Other costs: Are assumed to be a low percentage thus their change doesn't impact and is linear. It is assumed to be around 2.0% of its yearly revenues.

On the other hand, maintenance costs, renovations and insurance are non-linear:

- Maintenance: As seen in one of the cornerstones before, every component has a service life, and thus the more time a building is functional the higher the maintenance requirement it will be.
- Renovations: These are not linear, since they do not occur every year and address different scopes thus presenting gaps in the cumulative costs.
- Insurance: The older a building is, the more prone it is for claims thus insurance prices rise with age to compensate for their mathematical models. Usually, this value is empirically estimated in real estate ex-ante DCF's and is estimated between a 1% premium for new buildings up to 4% premium for old buildings of its total revenues.

5.5.1 Utilities

As mentioned before, 60% of buildings in Italy are classified as Class G, which for residential estimates an energy use of 160 kwh/m²/year and around 3 times less for a class A-B EPC Label. Additionally, the price of energy in Italy fluctuates from 0.20 EU/kWh to 0.25 EU/kWh, for this as an average of 0.225 EU/kWh is taken.

Thus, by multiplying these two values we have 36 EU/m²/year and applied to the case study a total of 36.000 EU/year, which amounts to 26.7% of the total expected revenue. This percentage in relation to the revenues is project specific, but through the analysis of diverse cap rates it can be assumed within the rage of 10% to 30%. We can also determine with the same calculations that a class A would amount to one third of the class G. Also, a study performed by Colliers (Agija Verdina, 2023), identified that heating costs of a new apartment are 50% to 38% of that of an old one.

It is important to bear in mind that these percentage only accounts for electricity, and it does not account also for possible efficiencies in the plumbing and sanitary system that may lead to less use of water (engendering savings and benefits for the society) and less energy losses, derived from less heating to the water necessary. It also does not account for newer appliances which have improved energy requirements in relation to their older counterparts.

To keep things simple and with a margin of error, it is assumed that utilities for a class G building equate to 25% of its total revenue. Contrarily, utilities for a class A-B are 12.5% of its total revenue.

Building Area	1000	m^2	Rent revenue	€ 135,000	EU
Class G	160	$kWh/m^2/y$	Consumption	€ 36,000	EU/y
Energy price	0.225	EU/kWh	%	26.7%	

Table 2 - Utilities summary for the case study. Class G building. Source: Own work.

5.5.2 Maintenance

There isn't simply an accurate formula or way to calculate maintenance costs of a real estate asset from an ex-ante perspective, because it not only depends on many characteristics linked to its construction but also on the landlord and its usage. For this reason, maintenance costs estimation is based on a range from the 'know-how' of the industry.

According to the research, this could be estimated either by price per m² ranging from old buildings from 20-40 EU/m² to new buildings 10-30 EU/m². Alternatively, maintenance can be defined from the revenues as 5% to 15% for new buildings and 10% to 20% for old buildings.

First Approach			
Rent Revenue	€	135,000	*EU*
Old Building		15.0%	*Maintenance relation*
Maintenance - Old	€	20,250	*EU/y*
New Build		7.5%	*Maintenance relation*
Maintenance - New	€	10,125	*EU/y*
Difference		50%	*Reduction*

Second Approach			
Area		1000	m^2
Old Building		30.00	*EU/*m^2
Maintenance - Old	€	30,000	*EU/y*
New Build		15.00	*EU/*m^2
Maintenance - New	€	15,000	*EU/y*
Difference		50%	*Reduction*

Table 3 - Maintenance costs on both approaches averaging ranges. Source: own work.

As appreciated (and expected) maintenance in old buildings is double in comparison to new builds. Thus, we can say this is an evolving percentage linked to an assets maturity in its service life. It is also important to account that there have been technological improvements to materials necessity for maintenance which also affect these initial rates. As an example, concrete mixtures performed nowadays by specialized companies offer specific characteristics that meet project needs and ensure its correct strength, while in 1960 these strict quality controls were not as precise. Another example is lighting, LED lighting offers not only improvements to energy usage but also have a much more significant life span in comparison to traditional lights.

For this reason, it will be assumed that for old buildings maintenance needs will start at 5% in its early life and end at recurrent 20% in its late life. In contrast, new builds will start at 2.5% in its early life and end at 15% in its late life. Late life is going to be defined as 100 years as per the cornerstone 4.4.1, since it was proven that maintenance and repairing after 100 years proved to yield the same results and not increased.

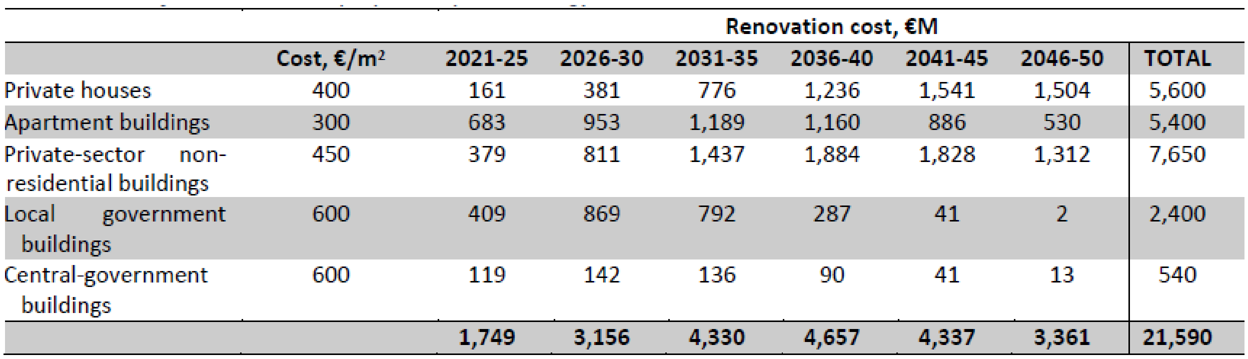
5.5.3 Renovation

As outlined before, building renovation does not occur in a planned manner. It is dependent on the obsolescence factors mentioned in earlier chapters, for example physical degradation leading to physical obsolescence or energy regulatory requirements leading to physical location obsolescence.

The aim of introducing renovation is to ensure the building and the model accounts for unplanned events and also externalities that will eventually impact a buildings LCC. Determining its impact from an ex-ante perspective is not straightforward, for this a paper published to the European Commission of Energy by the university of Tal Tech was used (TAL TECH - Arhitektuuri Instituut, 2020), this paper envisions a long-term strategy for building renovation and proposes an ambitious plan for large-scale renovation over time.

In order to measure in this paper, the costs of this project they did research and estimated costs of renovation of different typologies of assets. An important shortcoming for its usage in the present thesis is that these costs only account for energy savings and neglect other circumstances that may engender renovation. In fact, as per the paper:

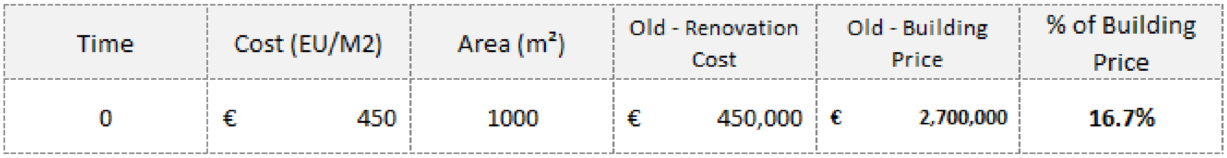
“As the aim of the strategy is to attain the climate goals, only the cost of the work to achieve energy savings is considered. Regarding other building categories, data on energy performance improvement work was gathered during the preparation of this strategy: For example, in apartment buildings, basically all work done improves energy performance. As for private-sector non-residential buildings, the strategy considers the renovation cost of the building envelope and building services systems, which is €600 per m² because two-thirds of the buildings need that kind of renovation.”



		Renovation cost, €M						
	Cost, €/m²	2021-25	2026-30	2031-35	2036-40	2041-45	2046-50	TOTAL
Private houses	400	161	381	776	1,236	1,541	1,504	5,600
Apartment buildings	300	683	953	1,189	1,160	886	530	5,400
Private-sector non-residential buildings	450	379	811	1,437	1,884	1,828	1,312	7,650
Local government buildings	600	409	869	792	287	41	2	2,400
Central-government buildings	600	119	142	136	90	41	13	540
		1,749	**3,156**	**4,330**	**4,657**	**4,337**	**3,361**	**21,590**

Table 4 - Cost of renovation as per (TAL TECH - Arhitektuuri Instituut, 2020)

As per the table above, the cost applicable to private non-residential buildings would be 450 EU/m², however the paper acknowledges this shortcoming and estimates around 33% for a proper renovation around at 600 EU/m². Following this same assumption, in our case study we have apartment buildings at 300 EU/m² which considering this would be 400 EU/m². Furthermore, these renovation costs account for 2019 prices, however, Construction price index (CPI) in Italy for 2019 was 106.9 and for 2024 is 120.3 according to ISTAT databases, that means an ≈ 12.5% increase, thus having now a cost of ≈ 450 EU/m².



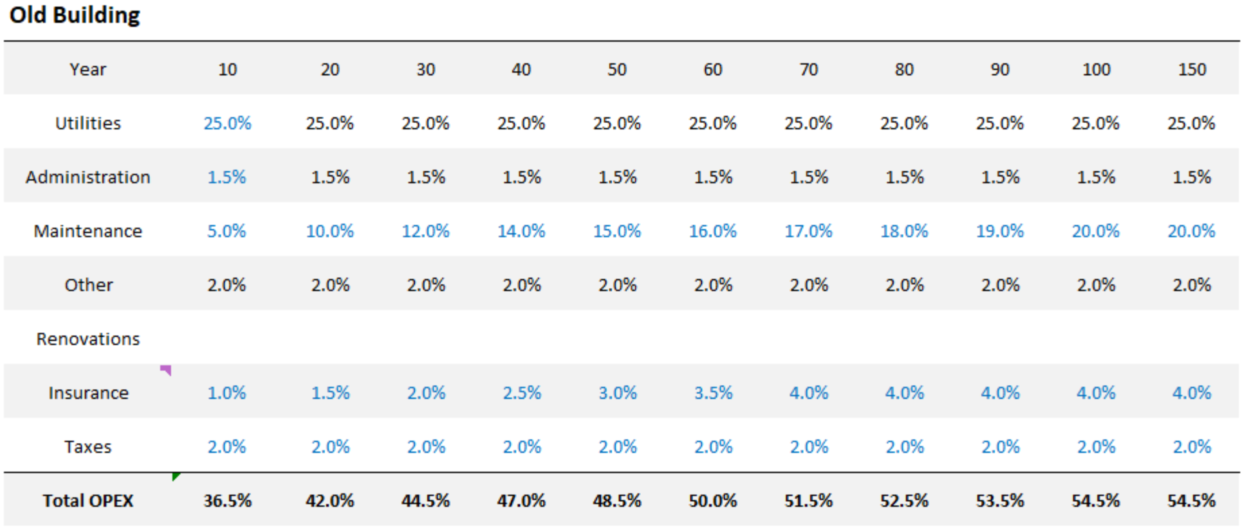
Time	Cost (EU/M2)	Area (m²)	Old - Renovation Cost	Old - Building Price	% of Building Price
0	€ 450	1000	€ 450,000	€ 2,700,000	**16.7%**

Table 5 - Renovation Costs for the case study time 0. Source: Own work.

Finally, it is necessary to account for periodicity, according to Figure 9 - Residential buildings by construction year. EU Building stock observatory (Europa.eu) & we can estimate that the average building stock age is around 40-50 years, thus the prior paper renovation costs addresses on average buildings with 40 years of age. The prior is important, because renovation needs are dependent on buildings age, the longer it has gone through without renovations it will end up costing more. For this reason, a periodicity of 40 years was considered in the model, although it is important to note that given a series of trials, as long as the constant is % the end results don’t change significantly.

5.5.4 Operational Inputs

After addressing each of the variables, and how are their numbers obtained or assumed, we have the following summary for an old building:



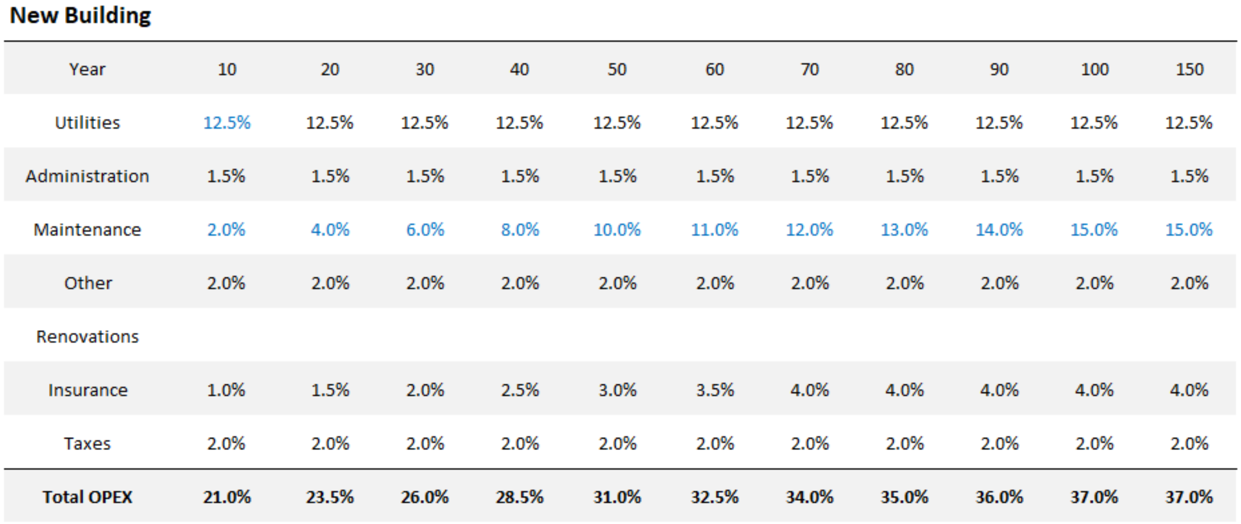
Old Building

Year	10	20	30	40	50	60	70	80	90	100	150
Utilities	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
Administration	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Maintenance	5.0%	10.0%	12.0%	14.0%	15.0%	16.0%	17.0%	18.0%	19.0%	20.0%	20.0%
Other	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Renovations											
Insurance	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.0%	4.0%	4.0%	4.0%
Taxes	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Total OPEX	**36.5%**	**42.0%**	**44.5%**	**47.0%**	**48.5%**	**50.0%**	**51.5%**	**52.5%**	**53.5%**	**54.5%**	**54.5%**

Table 6 - Old Building OPEX costs. Source: Mixed, the percentages shown are the compilation of sources according to Chapter 5.5 research, please refer to each section for source.

As mentioned, maintenance increases with buildings age from 5% to 20% in T=100, and insurance starts at 1% and ends at a 4% premium. Renovation's row is blank to explicitly indicate that it is accounted differently.

Given the prior information we can also propose a new building OPEX costs given engineering and technological improvements.



New Building

Year	10	20	30	40	50	60	70	80	90	100	150
Utilities	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%	12.5%
Administration	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Maintenance	2.0%	4.0%	6.0%	8.0%	10.0%	11.0%	12.0%	13.0%	14.0%	15.0%	15.0%
Other	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Renovations											
Insurance	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.0%	4.0%	4.0%	4.0%
Taxes	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Total OPEX	**21.0%**	**23.5%**	**26.0%**	**28.5%**	**31.0%**	**32.5%**	**34.0%**	**35.0%**	**36.0%**	**37.0%**	**37.0%**

Table 7 - New building OPEX Costs Source: Source: Mixed, the percentages shown are the compilation of sources according to Chapter 5.5 research, please refer to each section for source.

Main changes come from non-linear variables; thus, we can appreciate from an OPEX point of view that implementing new technologies even if costlier bring long-term improvements. In fact, we can see that on average a new building requires ≈ 65% of the OPEX of an old one.

It is worth noting that these tables are not constant, in fact, for every demolition project to be envisioned they have to be tailored according to the market values in each of these segments. However once done the model can be applicable to any asset.

Regarding renovations we have the following for an old building:

Renovation	0	40	80	120
Cost (EU/M2)	€ 450	€ 1,208	€ 3,244	€ 8,711
Old - Renovation Cost	€ 450,000	€ 1,208,279	€ 3,244,306	€ 8,711,167
Old - Building Price	€ 2,700,000	€ 7,249,672	€ 19,465,833	€ 52,267,005
Building Cost	16.7%	16.7%	16.7%	16.7%

Table 8 - Renovation Costs for an Old build

The initial value for renovation is adjusted by inflation depending on the year undertaken given the periodicity selected. Estimative building price based on a constant cape rate is presented to understand how it relates in percentage to the building cost. Later it is going to be presented renovation as periodical costs or as a percentage over the lifetime and the results are similar, although in reality if we have the option to renovate at T=80, we could instead choose to demolish thus avoiding this cost.

5.6 PROCEDURES

So far, the case studies descriptions and assumptions have been laid out, moreover a description of the lifecycle costs that an asset is subject to during its lifetime was outlined. These costs were broken down into linear or nonlinear and the underlying criteria for each was explained.

In parallel, the key inputs from a financial point of view for the initial asset were summarized and each of the operational expenditures were linked to these initial values, which apply for the old building and the new building.

Now that we have the initial key financial and architectural data, investment required, expected revenues, analysis timeframe and the costs that these assets will incur throughout their lifetime, we can build a Cashflow of the assets revenues and costs over the course of 150 years for each case scenario.

A model will be performed for each case; therefore, we can obtain the cumulative expenditure of the asset over the course of its lifecycle and compare one against the other. There will be multiple scenario analysis such as considering inflation as 0% and possible variations. Then the real scenario will be proposed where the old asset would be demolished and if what is proposed in the hypothesis holds true and finally perform an analysis of the Net present value of the investment to see its viability.

Finally, these results will be reviewed in conjunction with the environmental data outlined in the literature review to verify compliance, shortcomings and considerations along with the social framework.

6. CHAPTER 4 - RESULTS

6.1 BUILDING'S LIFECYCLE P&L WITHOUT INFLATION

6.1.1 Cashflow & Cumulative costs

The first step taken was to perform the old buildings cashflow over a 150-year period, considering the initial costs (Land, Design & Construction) and subsequently its operating expenses. Below it is possible to appreciate the cashflow per period (For pragmatic purposes, the cashflow doesn't show all time periods).

	Time (Years)	0	1	2	3	4	5	10	25	50	75	100	150
	Yearly Rent	€ -	€ -	€ -	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000
Design and Construction	Land	$ 300,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Design	$ -	$ 96,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Construction	$ -	$ 744,000	$ 1,260,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operations	Utilities	$ -	$ -	$ -	$ 56,250	$ 56,250	$ 56,250	$ 56,250	$ 56,250	$ 56,250	$ 56,250	$ 56,250	$ 56,250
	Administration	$ -	$ -	$ -	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375
	Maintenance	$ -	$ -	$ -	$ 11,250	$ 11,250	$ 11,250	$ 11,250	$ 27,000	$ 33,750	$ 40,500	$ 45,000	$ 45,000
	Other	$ -	$ -	$ -	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500
	Renovations	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Insurance	$ -	$ -	$ -	$ 2,250	$ 2,250	$ 2,250	$ 2,250	$ 4,500	$ 6,750	$ 9,000	$ 9,000	$ 9,000
	Taxes	$ -	$ -	$ -	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500
Totals Summary	**YoY**	$ 300,000	$ 840,000	$ 1,260,000	$ 82,125	$ 82,125	$ 82,125	$ 82,125	$ 100,125	$ 109,125	$ 118,125	$ 122,625	$ 122,625
	Cumulative	$ 300,000	$ 1,140,000	$ 2,400,000	$ 2,482,125	$ 2,564,250	$ 2,646,375	$ 3,057,000	$ 4,502,625	$ 7,602,000	$ 10,476,375	$ 13,947,000	$ 20,528,250
	Net Revenue	-$ 300,000	-$ 840,000	-$ 1,260,000	$ 142,875	$ 142,875	$ 142,875	$ 142,875	$ 124,875	$ 115,875	$ 106,875	$ 102,375	$ 102,375
	Cumulative	$ -	$ -	$ -	$ 225,000	$ 450,000	$ 675,000	$ 1,800,000	$ 5,175,000	$ 10,800,000	$ 16,425,000	$ 22,050,000	$ 33,300,000

Table 9 - Old Building Cashflow (without inflation). Source: Own work.

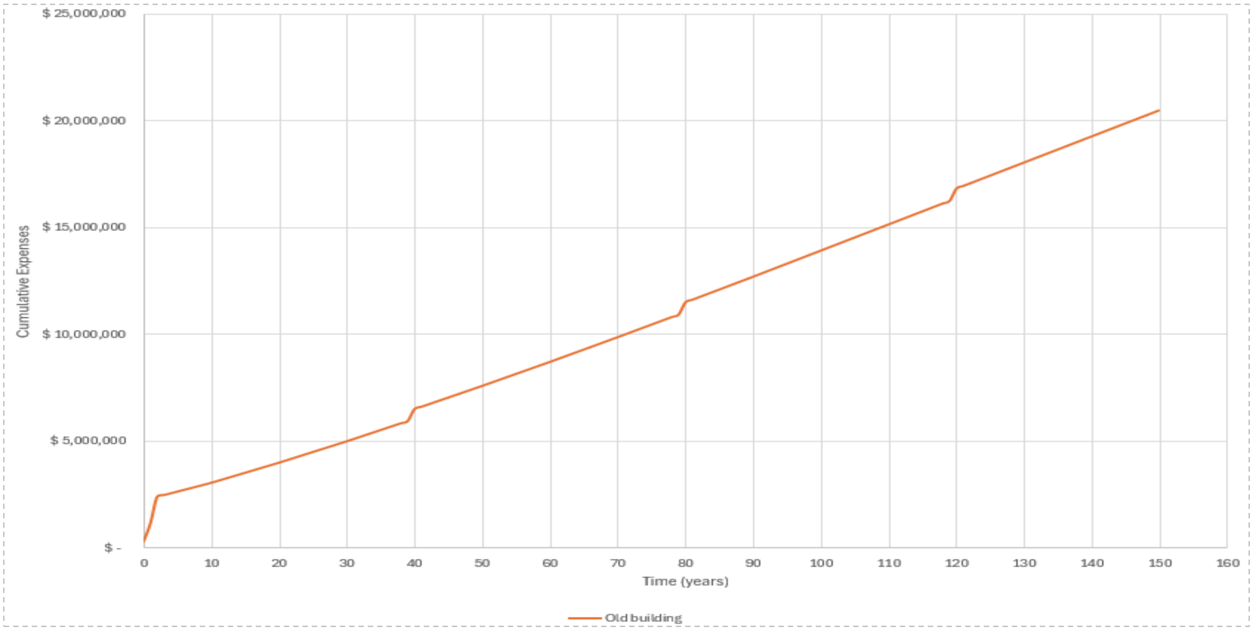
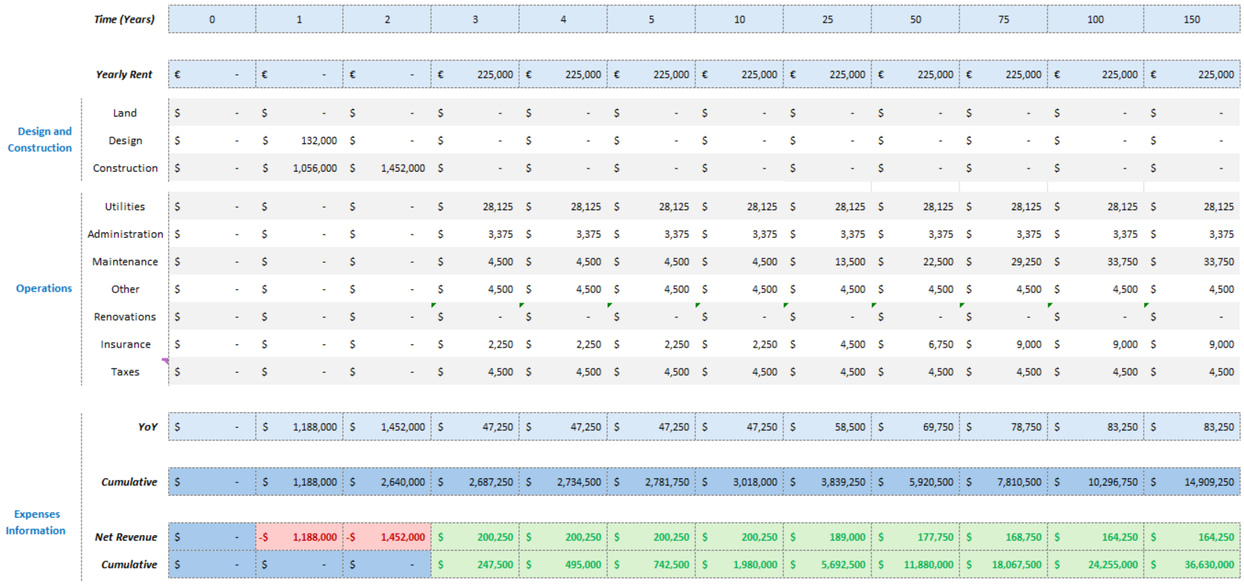


Figure 20 - Old building - Life cycle cumulative costs. Source: Own work.

Table 9 cashflow does not show inflation results, and thus revenues are not affected over time and also expenditures except from ageing performance. On dark blue is possible to appreciate in 'Cumulative' the Lifecycle cumulative costs of the building, note that at T=50 these amount to ≈ 3 times the initial investment, at T=100 ≈ 6, and at T=150 ≈ 8.5. This results are in congruency with various textbooks that indicate that operative life costs of a building amount up to 7 times of its initial cost. Note that renovations do not appear as they have a periodicity of 40 years.

Taking now a look to Figure 20, it can be appreciated at the start a spike which is the initial investment cost (Land, design and construction), and then constant costs over its lifetime with spikes due to renovations performed over its lifecycle. Now let's portray the same scenario for a new building.



	Time (Years)	0	1	2	3	4	5	10	25	50	75	100	150
	Yearly Rent	€ -	€ -	€ -	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000	€ 225,000
Design and Construction	Land	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Design	$ -	$ 132,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Construction	$ -	$ 1,056,000	$ 1,452,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operations	Utilities	$ -	$ -	$ -	$ 28,125	$ 28,125	$ 28,125	$ 28,125	$ 28,125	$ 28,125	$ 28,125	$ 28,125	$ 28,125
	Administration	$ -	$ -	$ -	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375	$ 3,375
	Maintenance	$ -	$ -	$ -	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 13,500	$ 22,500	$ 29,250	$ 33,750	$ 33,750
	Other	$ -	$ -	$ -	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500
	Renovations	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Insurance	$ -	$ -	$ -	$ 2,250	$ 2,250	$ 2,250	$ 2,250	$ 4,500	$ 6,750	$ 9,000	$ 9,000	$ 9,000
	Taxes	$ -	$ -	$ -	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500
Expenses Information	YoY	$ -	$ 1,188,000	$ 1,452,000	$ 47,250	$ 47,250	$ 47,250	$ 47,250	$ 58,500	$ 69,750	$ 78,750	$ 83,250	$ 83,250
	Cumulative	$ -	$ 1,188,000	$ 2,640,000	$ 2,687,250	$ 2,734,500	$ 2,781,750	$ 3,018,000	$ 3,839,250	$ 5,920,500	$ 7,810,500	$ 10,296,750	$ 14,909,250
	Net Revenue	$ -	-$ 1,188,000	-$ 1,452,000	$ 200,250	$ 200,250	$ 200,250	$ 200,250	$ 189,000	$ 177,750	$ 168,750	$ 164,250	$ 164,250
	Cumulative	$ -	$ -	$ -	$ 247,500	$ 495,000	$ 742,500	$ 1,980,000	$ 5,692,500	$ 11,880,000	$ 18,067,500	$ 24,255,000	$ 36,630,000

Table 10 - New building Cashflow (without inflation) Source: Own work.

Table 10 - New building Cashflow (without inflation)Table 10 requires additional comments. The first thing that can be appreciated it's the absence of Land cost, this is because such case assumes that the prior building was demolished and thus land ownership remains, however, it is important to note 2 important changes. The first one relates to improvements to design, engineering and materials, thus it is assumed not to discount land price but to make up for it with the investment, and the second one implies that new constructions are more efficient, thus the sellable area goes up from 75% up to 85% due to architectural and structural improvements.

Given the prior we can then see that we have improvements, not only in the OPEX, but also in the revenues due to the ability to provide more area for rent, both at the cost of a higher initial investment. In this case we have at T=50 cumulative costs ≈2.25 of the initial investment, T=100 ≈ 4.0 and at T=150 ≈ 6.0, a significant improvement.

Even if these values seem low, it is of paramount importance to recall that these 2 scenarios imply an entire building replacement without generating additional increases to rent to its tenants, increasing built area or change the use.

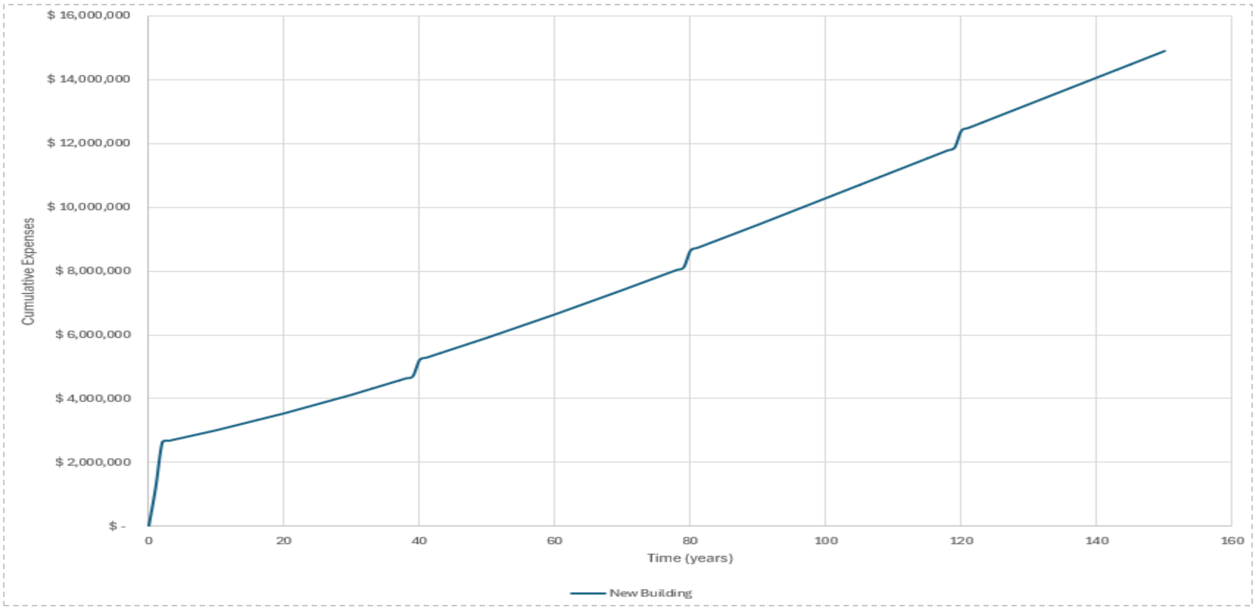


Figure 21 - New building - Life cycle cumulative costs. Source: Own work.

Looking at Figure 21, it follows the same pattern of the old building, albeit at reduced LCC OPEX. Therefore, with the results presented before now we can merge the results and see the comparison to the thesis initial hypothesis:

6.1.2 Alternatives comparison, DCF & Returns

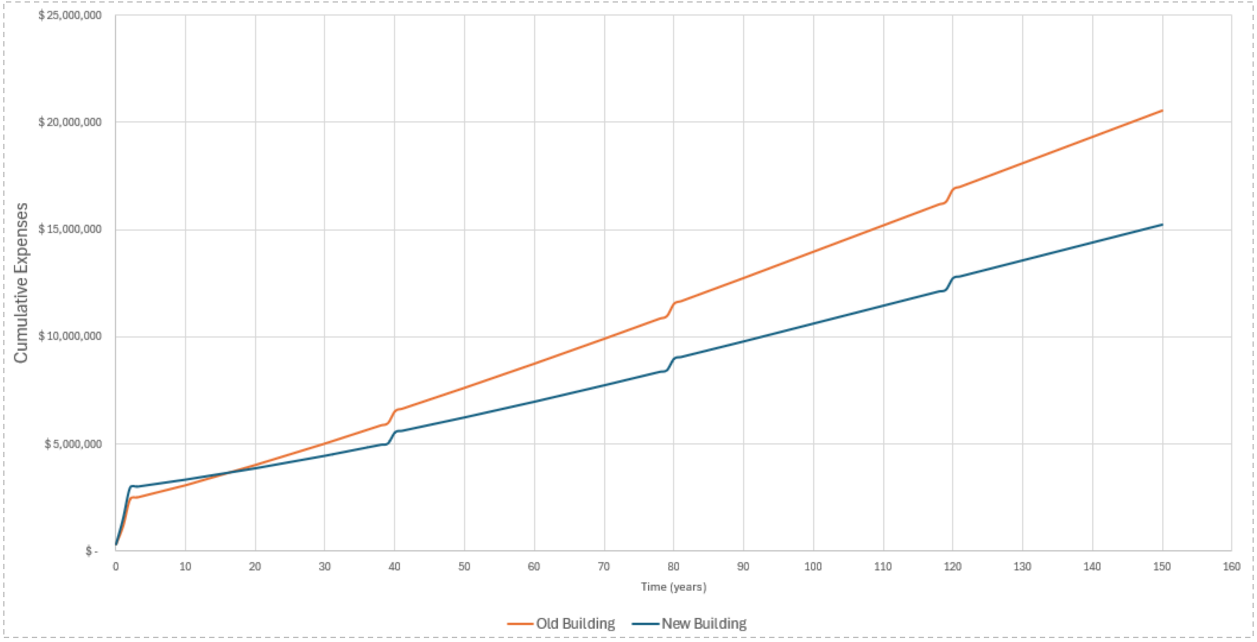


Figure 22 - Case study comparison over cumulative CC. Source: Own work.

Figure 22 is blunt, if we were to compare performances of an old building to a new building from the LCC point of view, their break-even point would happen in ≈ 16 years. Another further analysis, is trying to question what if the early costs could be invested in another project, to account for this a discounted cashflow of the costs is applied to both curves:

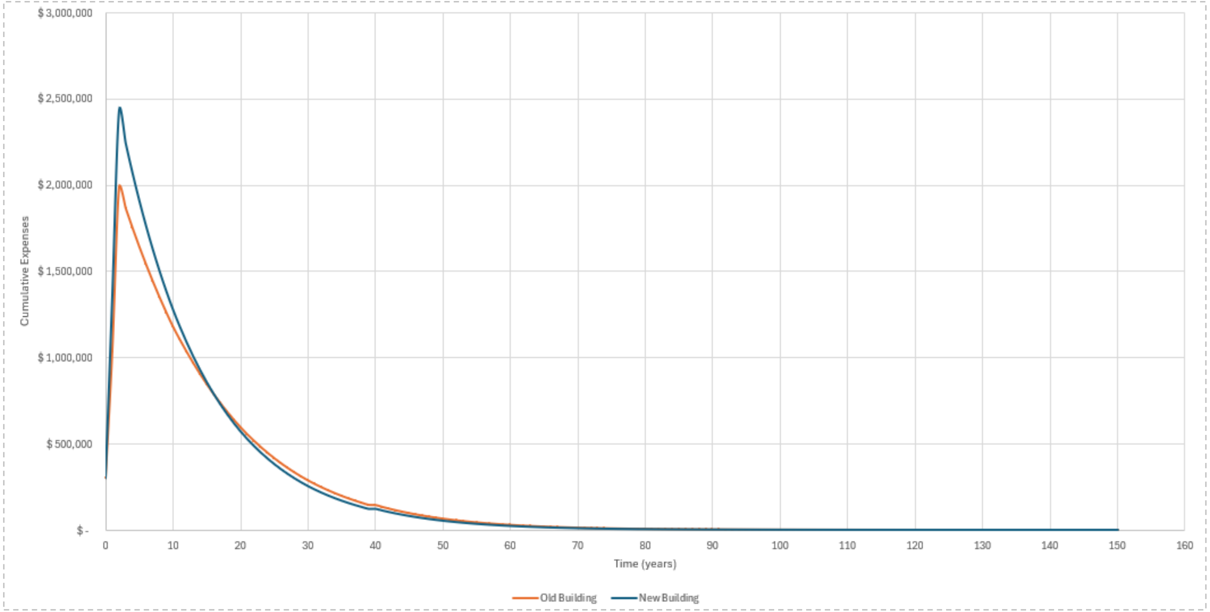
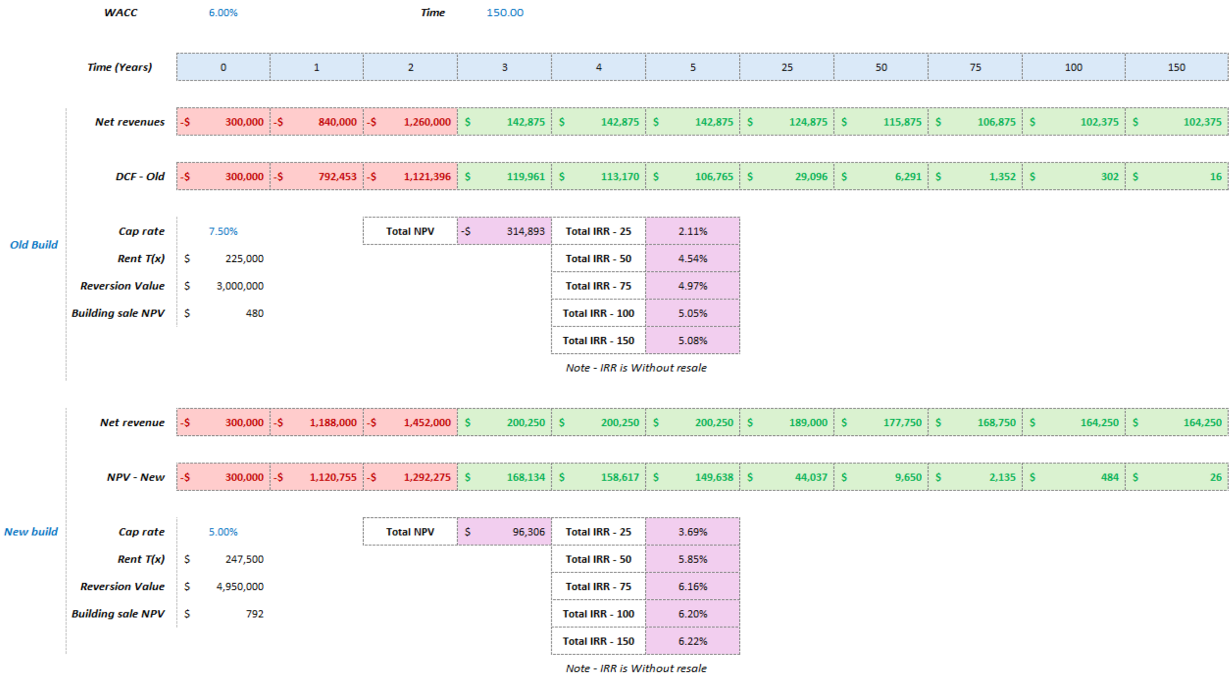


Figure 23 - Discounted costs flow of both case studies. WACC=10%. Source: Own work.

In this case it is assumed a WACC (weighted average cost of capital of 10%), and the breakeven point would be obtained at ≈18 years.

Now that it is clear what are the results from a cost perspective, it is also important to review the discounted cashflow accounting for revenues and the potential IRR in both scenarios.



WACC 6.00% **Time** 150.00

		0	1	2	3	4	5	25	50	75	100	150
	Time (Years)	0	1	2	3	4	5	25	50	75	100	150
Old Build	**Net revenues**	-$ 300,000	-$ 840,000	-$ 1,260,000	$ 142,875	$ 142,875	$ 142,875	$ 124,875	$ 115,875	$ 106,875	$ 102,375	$ 102,375
	DCF - Old	-$ 300,000	-$ 792,453	-$ 1,121,396	$ 119,961	$ 113,170	$ 106,765	$ 29,096	$ 6,291	$ 1,352	$ 302	$ 16
New build	**Net revenue**	-$ 300,000	-$ 1,188,000	-$ 1,452,000	$ 200,250	$ 200,250	$ 200,250	$ 189,000	$ 177,750	$ 168,750	$ 164,250	$ 164,250
	NPV - New	-$ 300,000	-$ 1,120,755	-$ 1,292,275	$ 168,134	$ 158,617	$ 149,638	$ 44,037	$ 9,650	$ 2,135	$ 484	$ 26

Old Build

Cap rate	7.50%	Total NPV	-$ 314,893	Total IRR - 25	2.11%
Rent T(x)	$ 225,000			Total IRR - 50	4.54%
Reversion Value	$ 3,000,000			Total IRR - 75	4.97%
Building sale NPV	$ 480			Total IRR - 100	5.05%
				Total IRR - 150	5.08%

Note - IRR is Without resale

New build

Cap rate	5.00%	Total NPV	$ 96,306	Total IRR - 25	3.69%
Rent T(x)	$ 247,500			Total IRR - 50	5.85%
Reversion Value	$ 4,950,000			Total IRR - 75	6.16%
Building sale NPV	$ 792			Total IRR - 100	6.20%
				Total IRR - 150	6.22%

Note - IRR is Without resale

Table 11 - Alternatives DCF & IRR Results (w/o inflation) Source: Own work.

For each scenario a DCF was performed with an assumed WACC of 6% over the envisioned timeframe. Furthermore, it is proposed that at the end of the timeframe the building will have a resale value that will also increase the profits. The NPV for a WACC of 6% turned out to be positive, for this an IRR was implemented to know the investment limit in each case.

As appreciated in Table 11, an IRR analysis was performed for common timeframes. It is perceived diminishing returns after year 75 in both cases. With a considerable IRR, repeating once again that the investments do not consider potential changes from its old revenue situation, however bearing in mind efficiency in OPEX and revenues increase because sellable area is higher.

6.1.3 Real Scenario Investment Analysis

Now that all information regarding the asset's lifecycle costs and revenues are presented, it is possible to simulate a real scenario where the decision of demolition is undertaken. As presented in Figure 22 we would reach this break point in 16 years, assuming that buildings are built at the same time, however this is not a realistic scenario.

A realistic scenario would envision that these curves fusion with each other, because they form part of the same investment. That is, the new building endeavor stems from the cumulative costs already incurred in the old building scenario. If the prior occurs, then the investment is feasible, and we could identify when the 'real break-even point' would occur in the overall 150-year period timeframe.

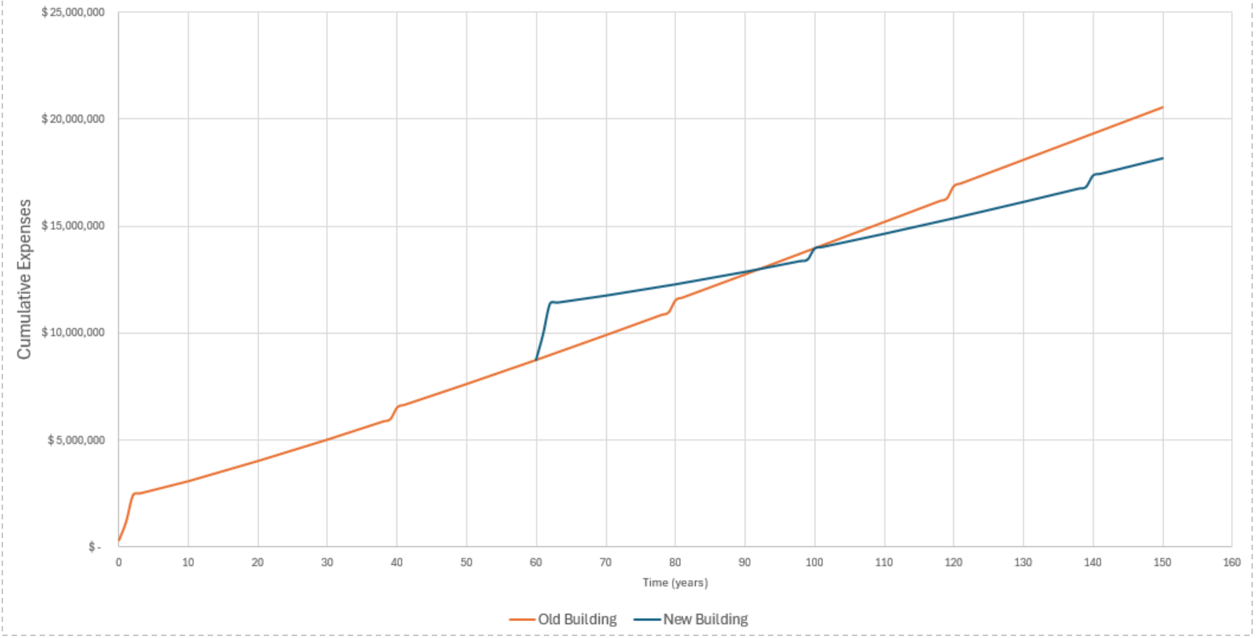
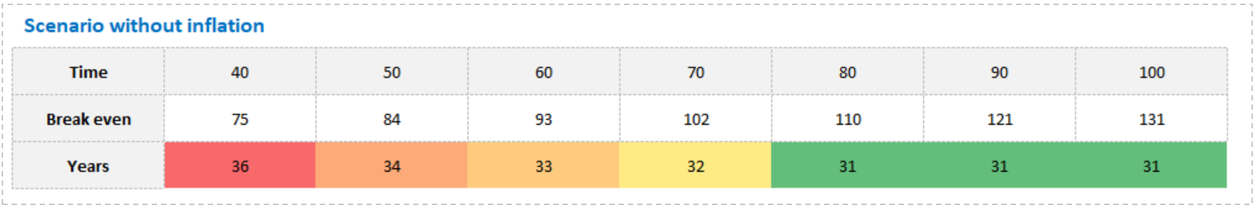


Figure 24 - Lifecycle cumulative costs of superseding investments of demolition – Payback period of 33 years. Source: Own work.

Figure 24 presents an example where the old building would be demolished at T=60, for this case we would break even in 33 years after the decision to demolish is taken. In virtue of the prior, multiple scenarios combining these decisions were made for every 10 years immediately before the first renovation was performed. Results are presented in Table 12 - Demolition financial recovery results



Scenario without inflation

Time	40	50	60	70	80	90	100
Break even	75	84	93	102	110	121	131
Years	36	34	33	32	31	31	31

Table 12 - Demolition financial recovery results. Source: Own work.

These results are dependent on the periodicity of hard renovations, as per the outlined assumptions we can identify that after year 79, results have decreasing returns. In other words, optimal timeframe would lie between 50 and 79 years, where the indicator for demolishing would be the necessity of a renovation.

Taking a look at the Discounted cashflow of the costs, we can also check that the period to recover them went up from the previous value to 33 years.

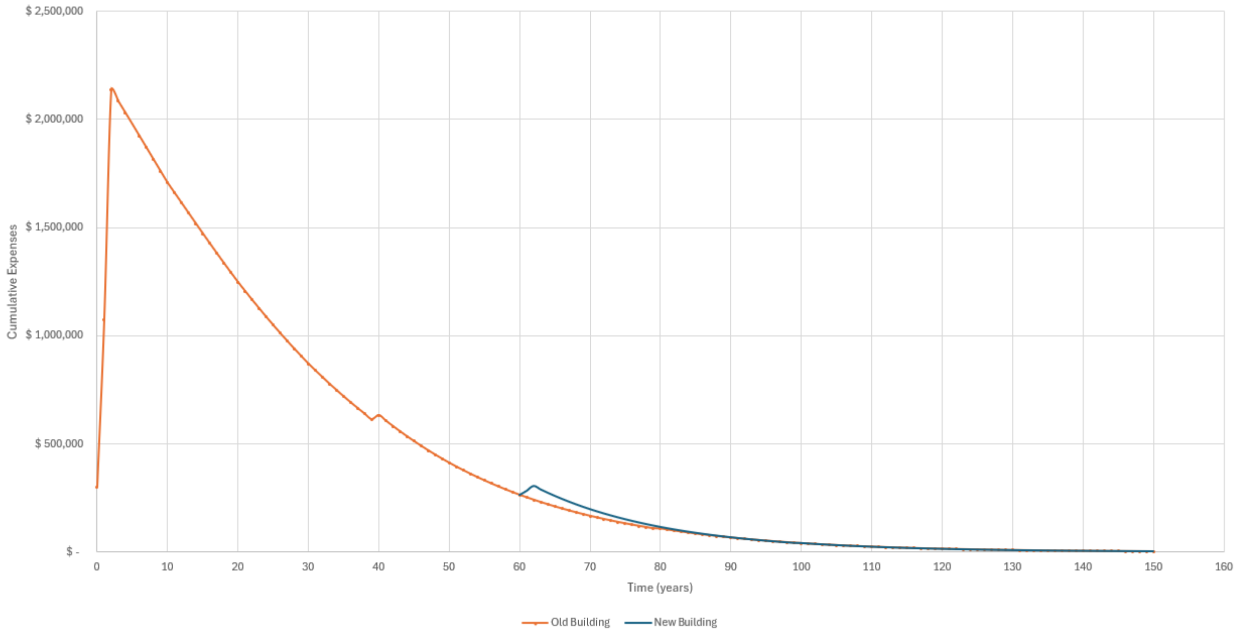


Figure 25 - DCF of costs without inflation both scenarios. Source: Own work.

6.2 BUILDING'S LIFECYCLE P&L WITH PRICE ADJUSTMENT

The same procedure and description will be carried out in this section, however now we will account for the inflation year over year. The inflation to be considered is constant, and it is assumed to affect costs and revenues in the same way, albeit in reality this will vary and in parallel this needs to be reviewed with the Construction prices index. This stems from a limitation as with many ex-ante investment appraisals and that is the inability to predict future values with known volatility as inflation among others.

6.2.1 Cashflow & Cumulative costs

The steps are the same as the prior but now account for inflation:

	Time (Years)	0	1	2	3	4	5	10	25	50	75	100	150
	Yearly Rent	€ -	€ -	€ -	€ 225,000	€ 230,625	€ 236,391	€ 267,454	€ 387,354	€ 718,132	€ 1,331,376	€ 2,468,297	€ 8,483,806
Design and Construction	Land	$ 300,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Design	$ -	$ 96,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Construction	$ -	$ 744,000	$ 1,260,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operations	Utilities	$ -	$ -	$ -	$ 56,250	$ 57,656	$ 59,098	$ 66,864	$ 96,838	$ 179,533	$ 332,844	$ 617,074	$ 2,120,952
	Administration	$ -	$ -	$ -	$ 3,375	$ 3,459	$ 3,546	$ 4,012	$ 5,810	$ 10,772	$ 19,971	$ 37,024	$ 127,257
	Maintenance	$ -	$ -	$ -	$ 11,250	$ 11,531	$ 11,820	$ 13,373	$ 46,482	$ 107,720	$ 239,648	$ 493,659	$ 1,696,761
	Other	$ -	$ -	$ -	$ 4,500	$ 4,613	$ 4,728	$ 5,349	$ 7,747	$ 14,363	$ 26,628	$ 49,366	$ 169,676
	Renovations	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Insurance	$ -	$ -	$ -	$ 2,250	$ 2,306	$ 2,364	$ 2,675	$ 7,747	$ 21,544	$ 53,255	$ 98,732	$ 339,352
	Taxes	$ -	$ -	$ -	$ 4,500	$ 4,613	$ 4,728	$ 5,349	$ 7,747	$ 14,363	$ 26,628	$ 49,366	$ 169,676
Totals Summary	**YoY**	$ 300,000	$ 840,000	$ 1,260,000	$ 82,125	$ 84,178	$ 86,283	$ 97,621	$ 172,372	$ 348,294	$ 698,973	$ 1,345,222	$ 4,623,674
	Cumulative	$ 300,000	$ 1,140,000	$ 2,400,000	$ 2,482,125	$ 2,566,303	$ 2,652,586	$ 3,117,454	$ 5,228,233	$ 12,855,070	$ 25,743,426	$ 54,075,789	$ 197,203,500
	Net Revenue	-$ 300,000	-$ 840,000	-$ 1,260,000	$ 142,875	$ 146,447	$ 150,108	$ 169,833	$ 214,981	$ 369,838	$ 632,404	$ 1,123,075	$ 3,860,132
	Cumulative	$ -	$ -	$ -	$ 225,000	$ 455,625	$ 692,016	$ 1,965,626	$ 6,881,496	$ 20,443,406	$ 45,586,429	$ 92,200,188	$ 338,836,047

Table 13 - Old Building Cashflow (price adjusted) . Source: Own work.

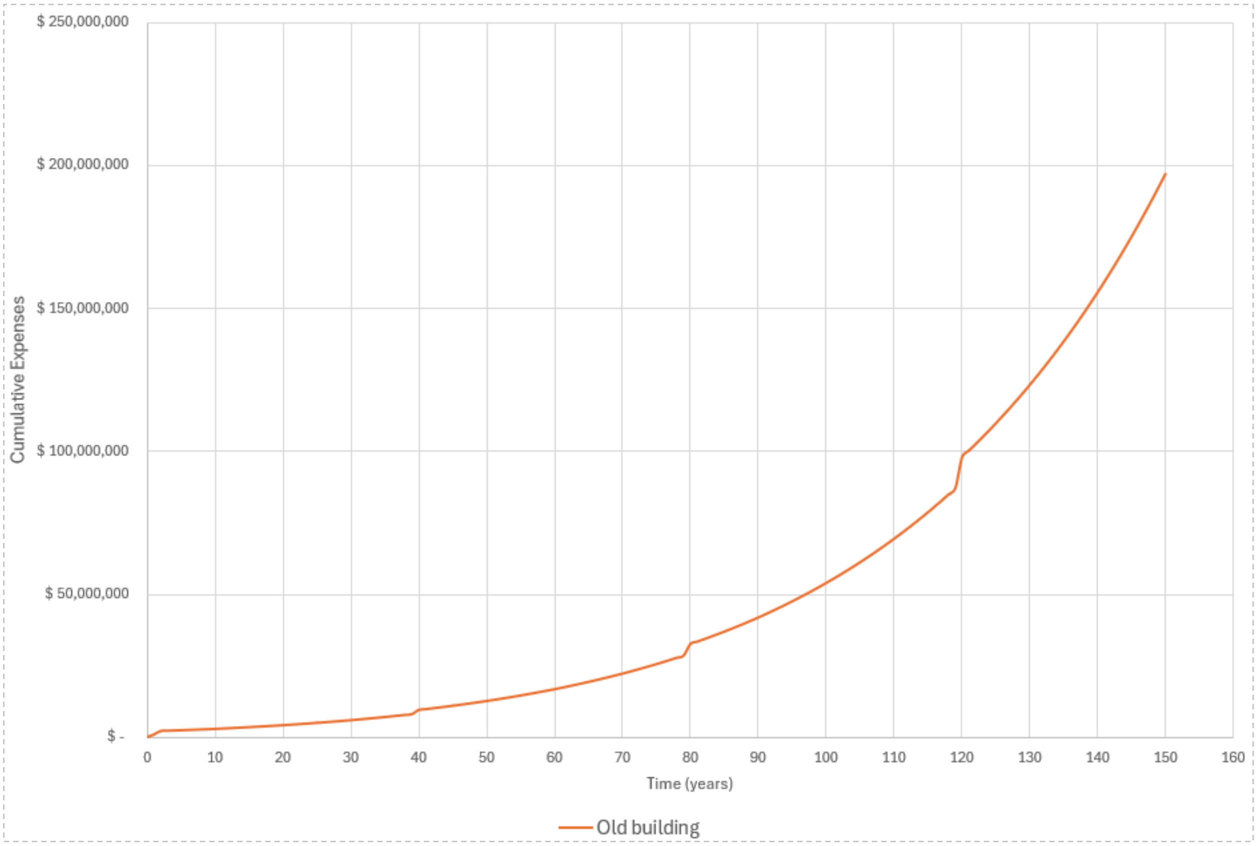


Figure 26 - Old building - Life cycle cumulative costs (Price adjusted) . Source: Own work.

As appreciated on both representations, results are as expected. Inflation adjustment year over year engenders compounding interest on the asset leading to increasing cumulative costs over the course of its service life, with values greatly overshadowing the no inflation scenario.

	Time (Years)	0	1	2	3	4	5	10	25	50	75	100	150
	Yearly Rent	€ -	€ -	€ -	€ 989,953	€ 1,014,702	€ 1,040,069	€ 1,176,743	€ 1,704,274	€ 3,159,629	€ 5,857,776	€ 10,859,989	€ 37,326,963
Design and Construction	Land	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Design	$ -	$ 580,772	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Construction	$ -	$ 4,646,178	$ 6,388,495	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Operations	Utilities	$ -	$ -	$ -	$ 123,744	$ 126,838	$ 130,009	$ 147,093	$ 213,034	$ 394,954	$ 732,222	$ 1,357,499	$ 4,665,870
	Administration	$ -	$ -	$ -	$ 14,849	$ 15,221	$ 15,601	$ 17,651	$ 25,564	$ 47,394	$ 87,867	$ 162,900	$ 559,904
	Maintenance	$ -	$ -	$ -	$ 19,799	$ 20,294	$ 20,801	$ 23,535	$ 102,256	$ 315,963	$ 761,511	$ 1,628,998	$ 5,599,044
	Other	$ -	$ -	$ -	$ 19,799	$ 20,294	$ 20,801	$ 23,535	$ 34,085	$ 63,193	$ 117,156	$ 217,200	$ 746,539
	Renovations	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Insurance	$ -	$ -	$ -	$ 9,900	$ 10,147	$ 10,401	$ 11,767	$ 34,085	$ 94,789	$ 234,311	$ 434,400	$ 1,493,079
	Taxes	$ -	$ -	$ -	$ 19,799	$ 20,294	$ 20,801	$ 23,535	$ 34,085	$ 63,193	$ 117,156	$ 217,200	$ 746,539
Expenses Information	**YoY**	$ -	$ 5,226,950	$ 6,388,495	$ 207,890	$ 213,087	$ 218,415	$ 247,116	$ 443,111	$ 979,485	$ 2,050,222	$ 4,018,196	$ 13,810,976
	Cumulative	$ -	$ 5,226,950	$ 11,615,445	$ 11,823,335	$ 12,036,422	$ 12,254,837	$ 13,431,597	$ 18,717,256	$ 41,518,312	$ 78,865,170	$ 167,630,731	$ 607,462,029
	Net Revenue	$ -	-$ 5,226,950	-$ 6,388,495	$ 881,058	$ 903,084	$ 925,661	$ 1,047,301	$ 1,431,590	$ 2,496,107	$ 4,393,332	$ 7,927,792	$ 27,248,683
	Cumulative	$ -	$ -	$ -	$ 1,088,948	$ 2,205,120	$ 3,349,196	$ 9,513,176	$ 33,304,850	$ 98,941,357	$ 220,627,773	$ 446,227,585	$ 1,639,888,105

Table 14 - New building Cashflow (price adjusted) . Source: Own work.

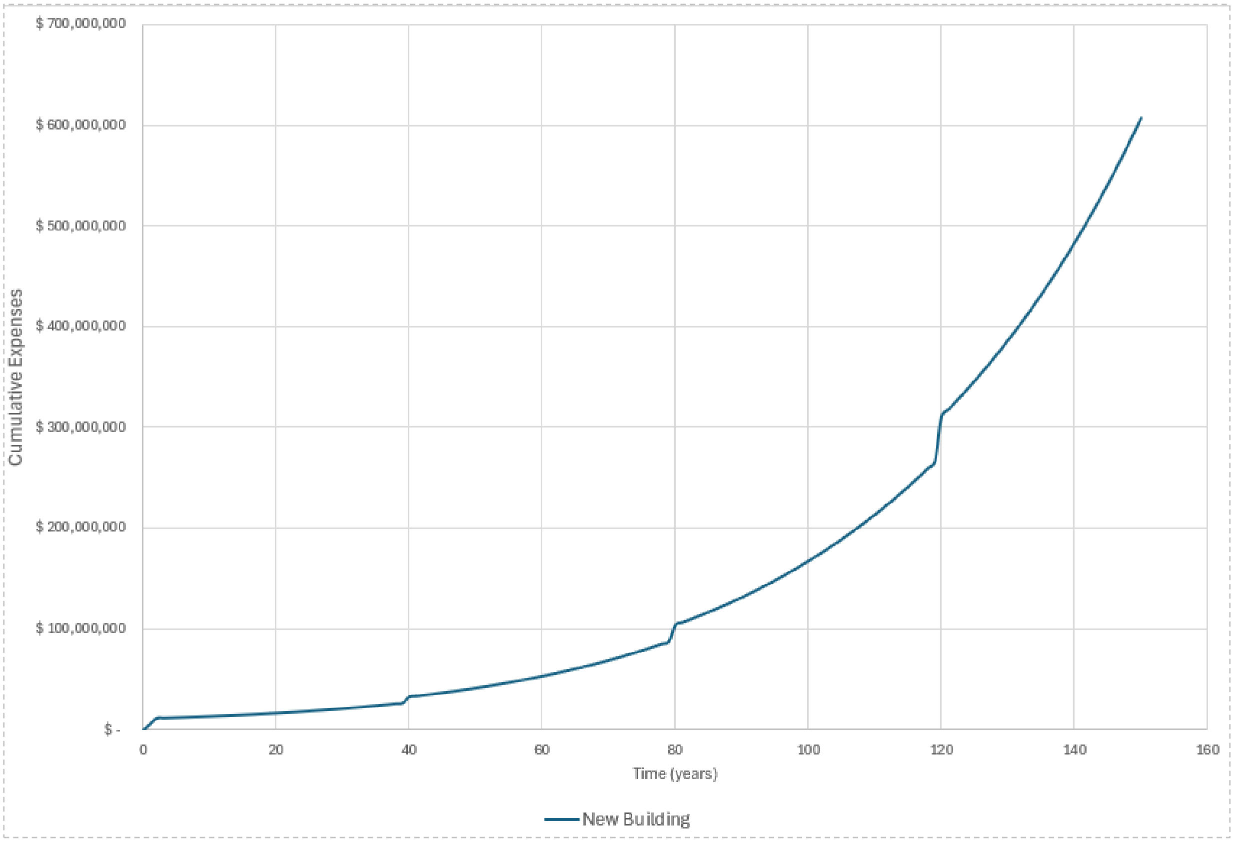


Figure 27 - New building - Life cycle cumulative costs price adjusted. Source: Own work.

6.2.2 Alternatives comparison, DCF & Returns

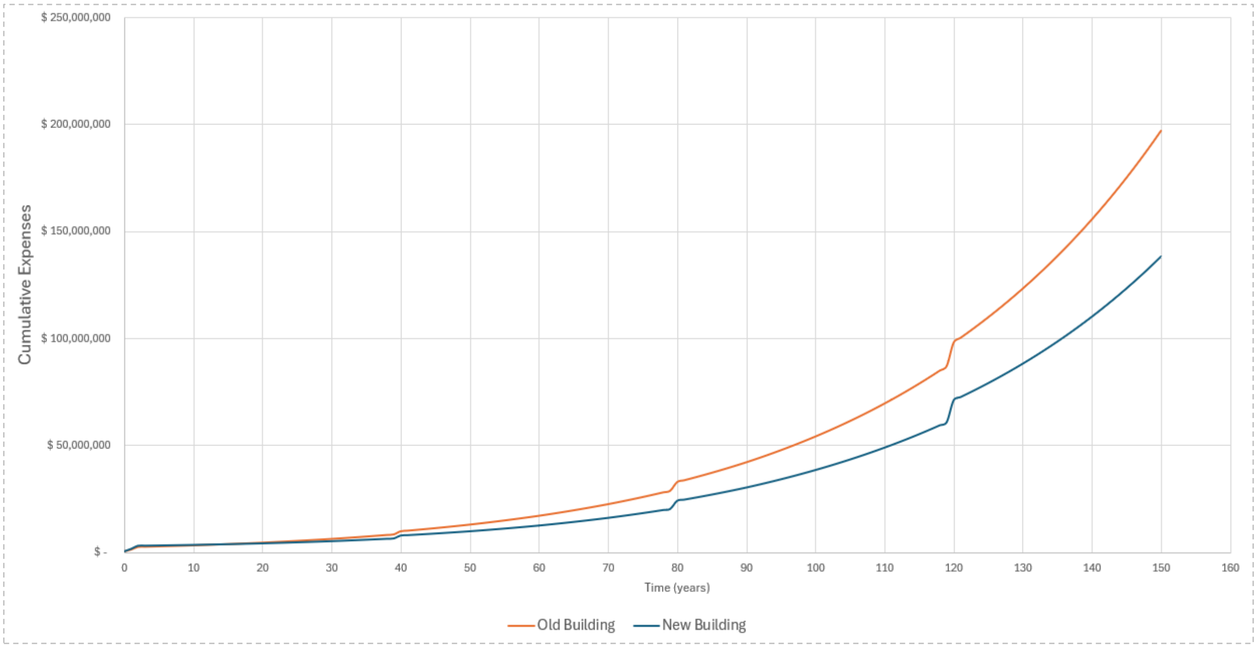


Figure 28 - Case study comparison over cumulative CC price adjusted. Source: Own work.

As expected, even accounting for inflation the slopes for both curves differ and still a break even at T=15. Another further analysis, is trying to question what if the early costs could be invested in another project, to account for this a discounted cashflow of the costs is applied to both curves:

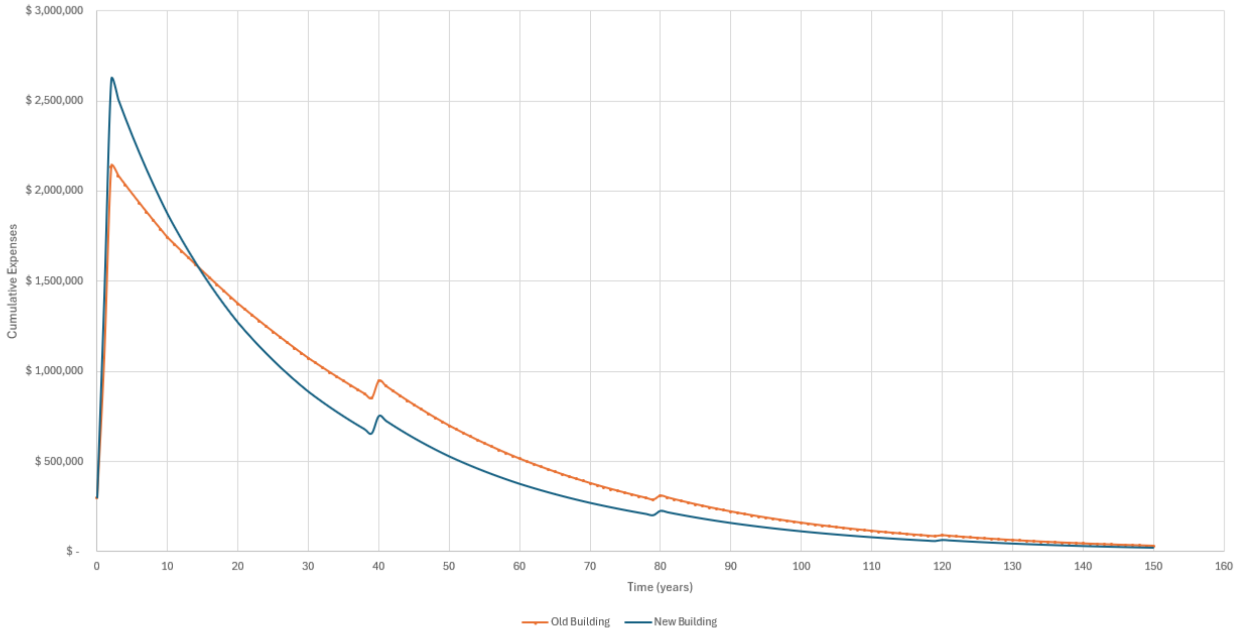
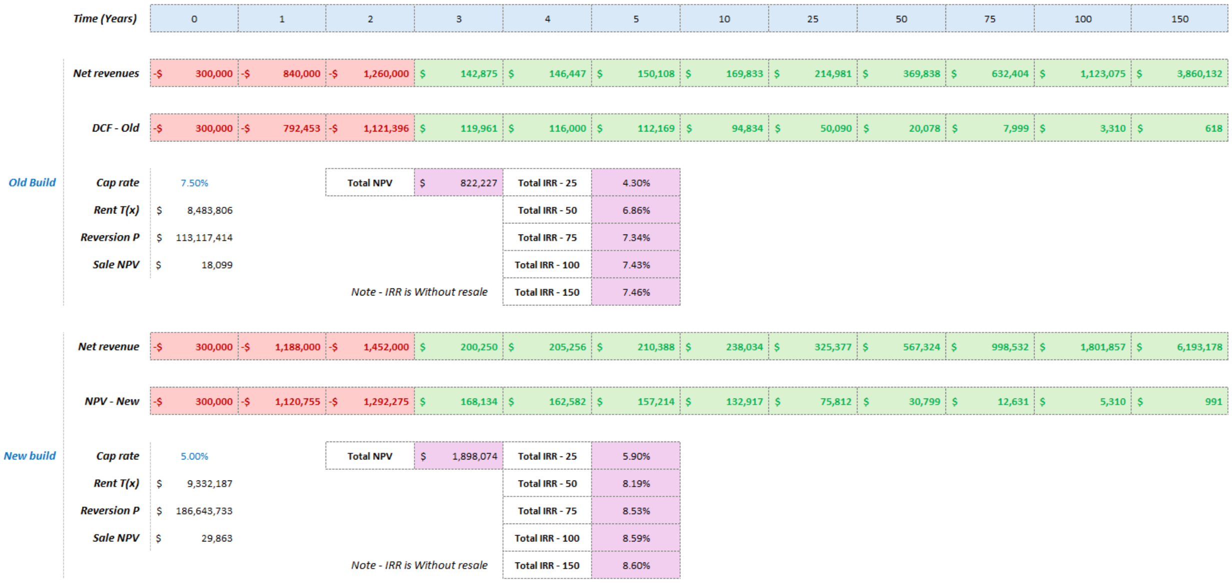


Figure 29 - Discounted costs flow of both case studies price adjusted WACC 6%. Source: Own work.

In this case it is assumed a WACC (weighted average cost of capital of 6%). Interestingly enough the break even point now is much shorter and presents at T≈15, 3 years earlier than the previous result.

Now that it is clear what are the results from a cost perspective, it is also important to review the discounted cashflow accounting for revenues and the potential IRR in both scenarios.



	Time (Years)	0	1	2	3	4	5	10	25	50	75	100	150
	Net revenues	-$ 300,000	-$ 840,000	-$ 1,260,000	$ 142,875	$ 146,447	$ 150,108	$ 169,833	$ 214,981	$ 369,838	$ 632,404	$ 1,123,075	$ 3,860,132
	DCF - Old	-$ 300,000	-$ 792,453	-$ 1,121,396	$ 119,961	$ 116,000	$ 112,169	$ 94,834	$ 50,090	$ 20,078	$ 7,999	$ 3,310	$ 618
Old Build	Cap rate	7.50%		Total NPV	$ 822,227	Total IRR - 25	4.30%						
	Rent T(x)	$ 8,483,806				Total IRR - 50	6.86%						
	Reversion P	$ 113,117,414				Total IRR - 75	7.34%						
	Sale NPV	$ 18,099				Total IRR - 100	7.43%						
				Note - IRR is Without resale		Total IRR - 150	7.46%						
	Net revenue	-$ 300,000	-$ 1,188,000	-$ 1,452,000	$ 200,250	$ 205,256	$ 210,388	$ 238,034	$ 325,377	$ 567,324	$ 998,532	$ 1,801,857	$ 6,193,178
	NPV - New	-$ 300,000	-$ 1,120,755	-$ 1,292,275	$ 168,134	$ 162,582	$ 157,214	$ 132,917	$ 75,812	$ 30,799	$ 12,631	$ 5,310	$ 991
New build	Cap rate	5.00%		Total NPV	$ 1,898,074	Total IRR - 25	5.90%						
	Rent T(x)	$ 9,332,187				Total IRR - 50	8.19%						
	Reversion P	$ 186,643,733				Total IRR - 75	8.53%						
	Sale NPV	$ 29,863				Total IRR - 100	8.59%						
				Note - IRR is Without resale		Total IRR - 150	8.60%						

Table 15 - Alternatives DCF & IRR Results (w/ inflation) . Source: Own work.

Same scenarios were proposed for inflation to do a proper comparison. In this case the IRR still presents decreasing returns after year 75, albeit at a higher rate with at the same age from 6.2% (without inflation) to 8.5% (with inflation). Sales of the buildings appear significantly low, this stems because the WACC used to discount is almost 3 times the set value of inflation.

6.2.3 Real Scenario Investment Analysis

Now that all information regarding the asset's lifecycle costs and revenues are presented, it is possible to simulate a real scenario where the decision of demolition is undertaken. As presented in Figure 28,we would reach this break point in 15 years.

A realistic scenario would envision that these curves fusion with each other, because they form part of the same investment. That is, the new building endeavor stems from the cumulative costs already incurred in the old building scenario. If the prior occurs, then the investment is feasible, and we could identify when the 'real break-even point' would occur in the overall 150-year period timeframe.

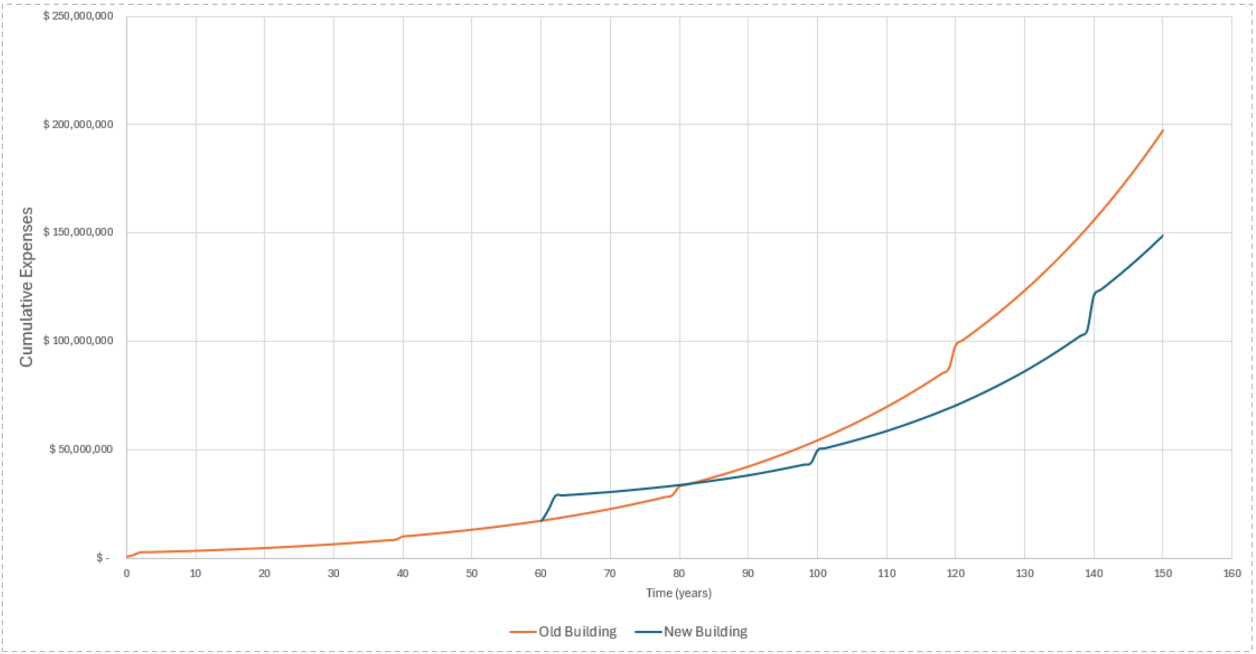


Figure 30 - Lifecycle cumulative costs of superseding investments of demolition with price adjustments. Source: Own work.

Figure 30 presents an example where the old building would be demolished at T=60, for this case we would break even in 22 years after the decision to demolish is taken. In virtue of the prior, multiple scenarios combining these decisions were made for every 10 years immediately before the first renovation was performed. Results are presented in

Scenario without inflation

Time	40	50	60	70	80	90	100
Break even	75	84	93	102	110	121	131
Years	36	34	33	32	31	31	31

Scenario with inflation

Time	40	50	60	70	80	90	100
Break even	66	80	82	93	103	118	121
Years	27	30	22	23	24	28	21

Table 16- Demolition financial recovery results with inflation (and previous case) . Source: Own work.

The results are quite interesting, there seems to be an important inflexion point at 60, obtaining diminishing returns up to T=100, where even if break-even years are less, it is still not worth the decrease. As with the previous case this results are highly dependent on renovations and are to be assessed case by case. In this scenario, the optimal timeframe would be between 60 to 75 years.

Taking a look at the Discounted cashflow of the costs, we can also check that the period to recover them went up from 15 years to 22 years (however it reduced in comparison without inflation scenario).

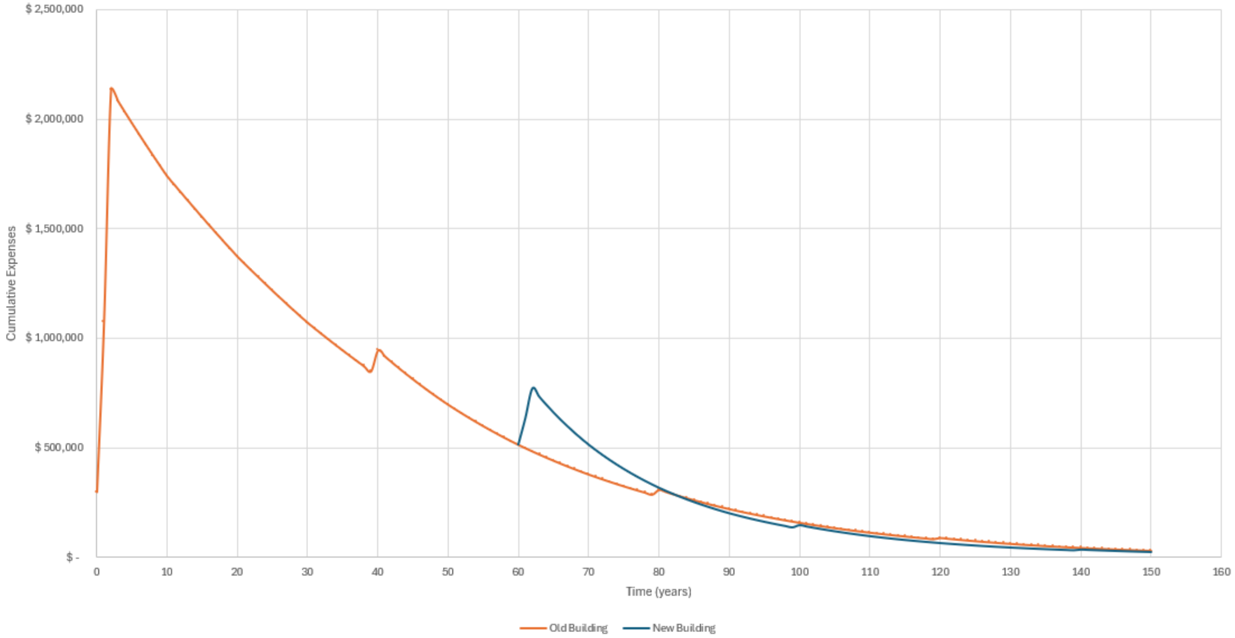


Figure 31 - DCF of costs with inflation both scenarios. Source: Own work.

7. ANALYSIS & DISCUSSION

7.1 ¿HOW TO ACCOUNT PROFITABILITY?

7.1.1 Hypothesis Comparison & Results

As outlined in the hypothesis section, the initial thought envisioned that the implementation of engineering, materials and new technologies would derive in building efficiencies during operations, so that eventually a new build investment would generate a payback period only accounting for cost savings in comparison to an old building.

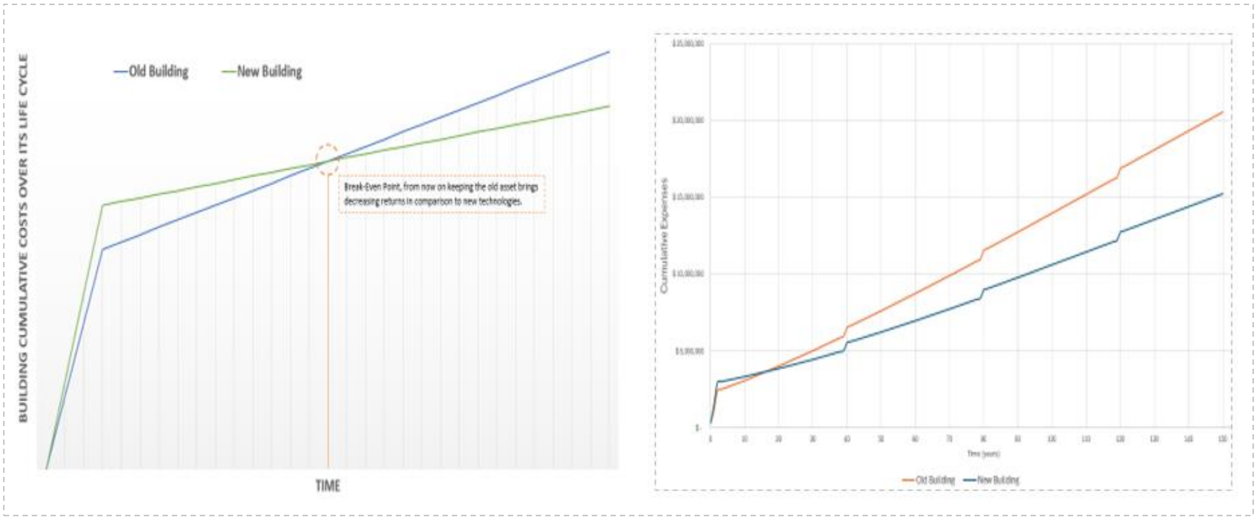


Figure 32 - Hypothesis and Case comparison. . Source: Own work.

According to the case study performed it was concluded that the payback period materializes as forecasted, so long as the cumulative costs slope of thew new option is lower than the prior. For the case study it even occurs faster than anticipated, when not considering inflation, the payback is at year 16, while with inflation it occurs at year 15.

It was also acknowledged that this scenario was not realistic, since if we were to replace an old building with a new one, it was a given that the initial investment and cumulative costs up until that point of the old building had already been committed.

To counter this, a real scenario where both of the investments are cumulatively added was performed so we could grasp from a total cumulative cost point of interest its feasibility given the initial investment of the old building, and it was proven that no matter the time defined for the old building's demolition, eventually the payback materializes due to the differences in slope.

As per figures 24 and 30, displayed again below, it was possible to show in both scenarios how cost efficiencies derive in improved profitability. For figure 24, when there is no inflation considered, the payback when demolishing at T=60 is 33 years, and at T=79 (1 year prior to renovation) is of 31 years. When accounting for inflation, at T=60 the payback is of 22 years, and at T=79 of 24 years. However, how would a curve showing the payback period against demolition time look like?

Figure 24 - Lifecycle cumulative costs of superseding investments of demolition – Payback period of 33 years. Source: Own work.

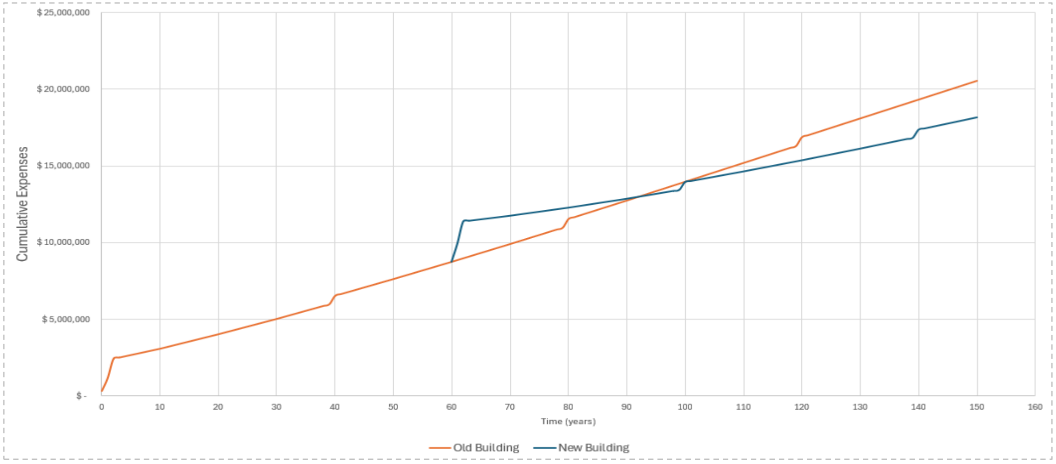
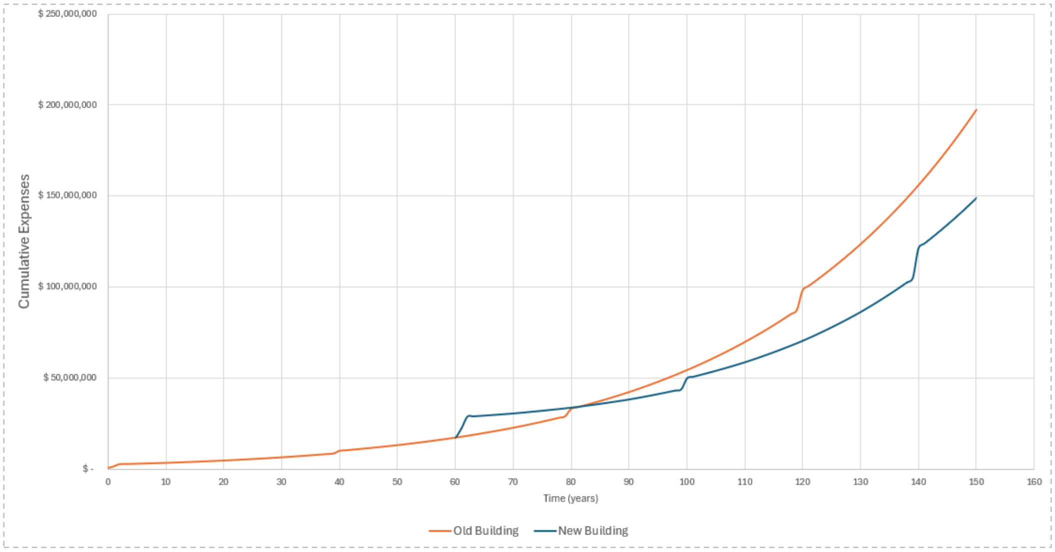


Figure 30 - Lifecycle cumulative costs of superseding investments of demolition with price adjustments. Source: Own work.



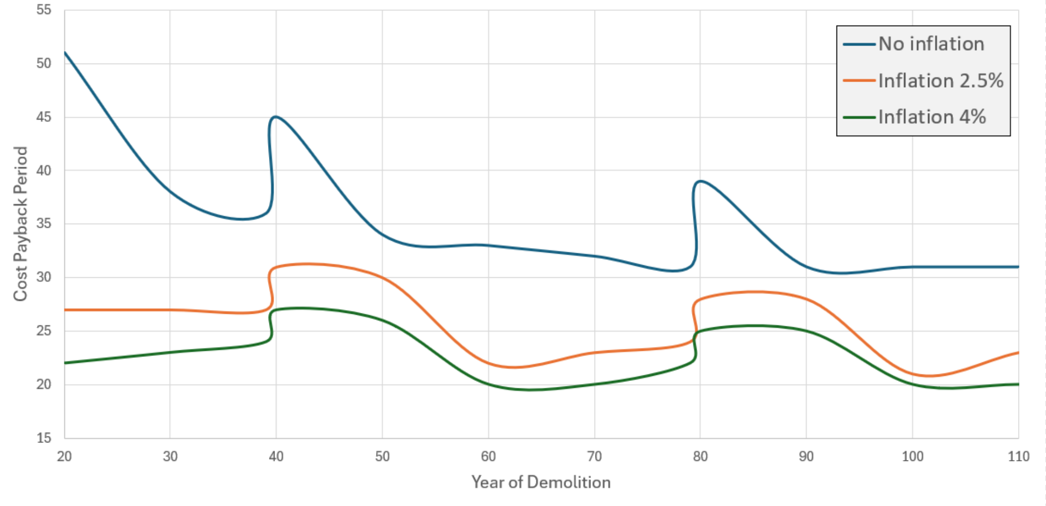


Figure 33 - Demolition VS. Expected payback period. Source: Own work.

Figure 33, accounts for each curve the cumulative costs of an old building + new building and what would be the payback period at each year of demolition. As an example, for the case with no inflation: At year T=50 we would demolish the old building, which derives that the payback period from the new development will occur in ~34 years.

The peaks in the graph represent renovations, it can be grasped that if there were no renovations to occur this curve would take an inverted logarithm shape, just as in the case of the first cornerstone! Inflation option dampens the curve because of compound interest gains over the years.

Lastly, a third option account for an inflation of 4% was considered to see if the curve tendency would change, however it seems to portray constant behavior with a tendency to lower slowly in the long-term.

7.1.1.1 Future Models

Since investors want to minimize their risk exposure and also aim for higher IRR, it was further shown that demolition decision periods lie between 50 and 75 years, and that if a hard renovation were to be considered in this timeframe, demolition and reconstruction would prevail from a financial point of view. This is further strengthened by Figure 33 where it can be seen that between T=60 and T=75 payback periods would be lower.

It is worth noting that this model is highly dynamic and requires specific customizations case by case. It comprises the same limitations of Real Estate and Construction, which is that it is something strictly related to local parameters, conditions, restrictions, and environment. A significant number of variables are dependent on location and asset class.

While this thesis envisioned that through cost savings one could improve economic performance, it does not take into consideration multiple benefits stemming from new developments. For example, re-development in uses that by their own increase revenues through a use change or replacing a series of buildings for a more complex project. In those cases, while profit must be accounted for it will most likely be imposed as a given, the most important part is proving that by cost efficiencies it would derive benefits from their demolition.

Thus, for the financial aspect there should be always cumulative costs and revenues modelling from the asset(s) envisioned to be replaced and how would a new development enter into the cumulative cost cycle. One important caveat would be to keep track of hard renovations, as these most likely signify milestones on whether a short-term upkeep is performed, or a replacement is preferable.

7.1.2 A further look into its applicability

This model can be easily applied to most real estate asset classes, one exception would perhaps be Hospitals or specialized assets that offer services whose operational expenditure is highly complex and volatile, in those cases given that the real estate asset owner has built the old building curve, it would be feasible to construct the new curve given an in-depth study and possibly inclusion of econometrics and risk analysis in their parameters. As an example, a specialized machine such as a nuclear image generator that has high impact on costs could potentially be replaced by a new one with different specifications, but the consequences stemming from its implementation need to be assessed ex-ante, that includes maintenance and energy requirements, and in a complex environment such as a hospital it would comprise a significant number of assets.

Let us now give another look at the model and assume there have been no significant improvements to materials, engineering, or technology in the last 50 years, or at least they are minimal. When trying to model these conditions, we would see that if we try to replace a building with class G energy, high maintenance and 75% of sellable area with one of the same characteristics but with medium maintenance, we will realize that the payback period will be unfeasible or not attractive.

This is the exact purpose of the model and of the thesis, that even if we want to account for sustainable and social solutions, we must not overlook the positive consequences stemming from engineering, materials, and technologies advancements. Of course, it is necessary to look at the financial model from a sustainable and social point of view which we will address in the next sections.

7.2 ¿HOW TO ACCOUNT SUSTAINABILITY?

7.2.1 The first cornerstone

Now that we compared results against the hypothesis, it is necessary to also take a look at results from literature review references. In the first cornerstone presented, we had the following conclusions:

- 1. For a given house demolition cumulative embodied energy impact lessens significantly at T=50 and reaches a stabilized impact after T=100.
- 2. Recurrent embodied energy materialized through constant renovations on the long-term becomes constant, simply because every building component has a maximum service life. Furthermore, at T=75 recurrent renovations embodied energy match initial construction.
- 3. By combining the energy impacts of embodied energy and recurrent energy, we identify that at T=50 a significant decrease occurs remaining constant up until T=70, then from T=70 to T=100 and from T=100 shows constant impact.
- 4. Finally, for the given case accounted in that paper, it demonstrates that the energy savings between demolition and constant renovation yield equivalent results in longer timeframes, specifically between [50 –70), (70-100) and (100+]

When looking at the financial model, on a real scenario investment basis we can identify quite a similar trend. In other words, we find the following:

- 1. Payback periods behave the same way as portrayed in the case study, that is an inverted logarithm curve takes place, where significant improvements start at T=50 and it continues to reduce until T=80, reaching constant values at T=100.
- 2. When looking at the expected investment IRR – IRR at T=50 is circa 50% higher than at T=25, indicating that T=25 from the investment perspective is too early for replacement. We can find further optimal results at T=75 and a stabilization until T=100 where increments are minimal.

These results are astounding, as they hold the same ranges of this study! In fact, according to this case study if the demolition would occur at T=75 not only it would be possible to achieve an IRR equivalent to 8.5% by demolition but it would actually be as sustainable as constantly renovating, so we would ensure that the decision would actually yield the same results, thus bringing same sustainability as prior but incrementing profits.

In virtue of the prior an important milestone is verified here regarding embodied energy (EE), which mathematically can be expressed as:

$$\text{If } (\Sigma\, Construction\ EE\ \leq\ \Sigma\ \text{Renovation EE})\ then = Replacement\ is\ Sustainable$$

This would ideally mark a boundary in the financial model. As an example, in Figure 13 this would hold true at T=75, thus then this is marked in the model as follows in red:

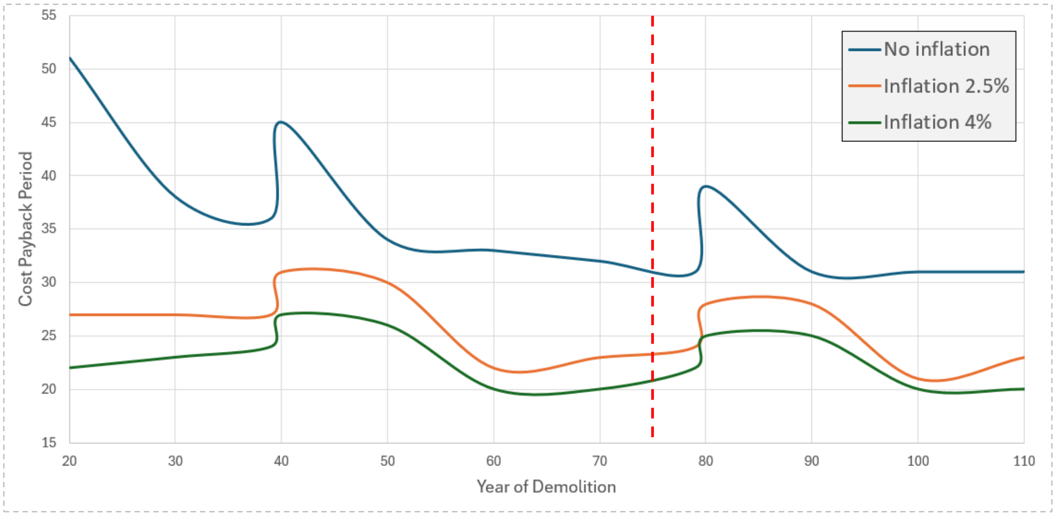


Figure 34 Demolition VS. Expected payback period sustainability restricted (red line). Source: Own work

This would imply that considering the financial and sustainability factors, the ideal moment to demolish would be between T=75 and T=79, before incurring any renovation. However, the T=75 doesn't assume building efficiencies, hinting at a earlier date if taken into account.

An important note – The thesis first cornerstone is steadfast in that these graphs do not account for technological, engineering or material advancements; In other words, even if the slopes of the 2 buildings were to give insignificant cost efficiencies, it would still be from a sustainable point of view feasible to replace such asset at T=75.

2 last caveats to note that will be addressed later, the first one concerns the cornerstone study applicability to different assets because in its current status is limited; And second refers to implementing new engineering solutions to make the sustainability solution a positive result rather than the same.

7.2.2 The second cornerstone

According to this section, in Figure 14 it presented a possible payback time for carbon investment of 30 years, and later on after the case studies were developed it was found that for these projects the payback time for the investment would actually be 33 years for a concrete building, and 22 years for a wooden building.

One short coming to that study is that the payback time is presented assuming equal start of investment for the options, it would need to further do a cumulative carbon investment curve so as to determine which would be the new years for the payback investment. In any case mathematically speaking it is simple, as long as there is a slope improvement the payback will materialize. Doing an approximation guess (according to the slopes presented) for the wooden building the cumulative payback period would occur at T≈75 and for the concrete building at T≈85.

- If we compare the initial payback period at T=0, we can see there are crucial differences between the financial and sustainability facets, almost doubling the age.

- Moreover, if we account for cumulative carbon investment the payback period would occur at T≈75, assuming that the demolition takes place just before the spike at T=25. That is almost 50 years for a payback. However, if the replacement occurs at T=50 the payback due to the decreasing returns principle as happened in the financial model.
- Finally, these results would further improve if the recurrent embodied energy for renovations were considered, since in this study only initial embodied energy and recurrent embodied energy of operations were taken into account.

The case study referenced in the second cornerstone is important as it envisions a project on a school of considerable size. Moreover, now it introduces the concept of material sustainability by offering wood as a solution after demolition.

In fact, this thesis cornerstone must become a complement to the first one as it addresses the cumulative carbon due to operations, something that the first one did not consider. For future studies to assess a complete spectrum of energy impact the whole Life cycle cost for Carbon investment must be considered. We can conclude the following for the cumulative carbon investment:

$$Cumulative\ Carbon\ = Initial\ EE + Recurrent\ (Operations + Embodied\ Renovations)$$

Moreover, this formula triggers another consideration regarding the first cornerstone that is:

$$\text{If}\ (\Sigma\ Construction\ EE +\ \Sigma\ Operations\ E_{New}\ \leq\ \Sigma\ \text{Renovation EE} +\ \Sigma\ Operations\ E_{Old}) = True\ , Then\ demolition\ is\ sustainable.$$

Ideally, this would be seen in Figure 13 with another bar added accounting recurrent operations energy for a case where efficiencies are not improved in contrast to a case where they are improved through technological advancements.

Even though this evaluation is yet to be made, it can be theorized from a mathematical point of view, that given that new technologies, engineering and materials bring improvements this would signify that the stated T=75, would diminish but not increase! Simply because:

(1) $\Sigma\ Construction\ EE +\ \Sigma\ Operations\ E_{New}\ \leq\ \Sigma\ \text{Renovation EE} +\ \Sigma\ Operations\ E_{Old}$
(2) $If\ Operations\ E_{New} =\ Operations\ E_{Old}.then:$
(3) $\Sigma\ Construction\ EE +\ \Sigma\ Operations\ E_{Old}\ \leq\ \Sigma\ \text{Renovation EE} +\ \Sigma\ Operations\ E_{Old}$
(4) $\Sigma\ Construction\ EE\ \ \leq\ \Sigma\ \text{Renovation EE}$

And we know that: $Operations\ E_{New} \ll\ Operations\ E_{Old}$ thus the break-even from a sustainable facet would occur earlier than expected.

7.2.3 Materials & Replacement

As the second cornerstone addressed, the inclusion of sustainable materials in construction significantly impacts the payback period for carbon investments. To be blunt, from concrete to a wooden option it has obtained a 50% payback period saving. In reality, this will happen at a higher initial cost but as this thesis has demonstrated, the operative expenditure and environmental impact offsets these initial savings.

As a matter of fact, most of the European building stock that was built ~1970 have no more than 5 stories and given the recent engineering technologies of for example Cross Laminated Timbe solutions, where buildings up to 10 stories high are feasible this presents a potential solution to have not only net financial benefits, but also net sustainable benefits higher than 0.

From a long-term perspective strategy, it would be possible to replace buildings with these characteristics with their wooden counterparts. Yielding positive results financially and environmentally.

As mentioned also during the literature review, there are now diverse studies and solutions that aim to address the problem of demolition remnants or the process of deconstruction. This is paramount because, this thesis along with the cornerstones prove that it is possible to achieve sustainable positive net benefits from building replacement. That means that the old building and its components, if treated adequately, are an added value to the population and its deconstruction should be proposed to take advantage of it.

7.3 ¿HOW TO ACCOUNT THE SOCIAL FACET?

Up to this point, the framework has embraced both economical and sustainable aspects when undertaking a demolition decision from a mathematical point of view. And as it has been described before, projects have to be sustainable from all ESG aspects, even if the economic and environmental were to be sound there may be negligible, equal or significant social impacts to consider.

While it is the objective to address a few important social aspects, it is acknowledged that within this thesis these will be analyzed at a high level and not in depth. In fact, the social facet comes to be quite subjective, profound and encompasses a myriad of considerations and layers for which even a mathematical model would not be realistic to determine.

Bringing back the demolition determinants developed and mentioned earlier we have the following:

Physical reasons: Envisions Physical building obsolescence, Physical Quality, degradation, and technical performance.

Economic Reasons: Include owner profitability, resource capacity, business value, organizational motives.

Supply & Demand: Are as per the definition above and are linked to functionality, serviceability, and suitability. User oriented.

Social Reasons: Cultural, community motivations, Collective perceptions.

Externalities: Risks, Regulations, Legal requirements, and others.

Thus, in accordance with this we have within from a social aspect: the government (externalities), engineers & scientists (community motivations), circularity (supply & demand), and cultural heritage. Even among each of these mentions, there will be more to address or consider for future applications and procedures.

Finally, let us remember an important note before considering social impacts into demolition, that is:

"While physical service life can be prolonged, the end of service life will occur anyway <u>derived from users behavioral tendencies</u> either by Aesthetic, legal, technological, functional, economic, or social reasons."

In the end, an asset users determine its value through basic supply & demand and if this demand is not satisfied even if the building is perfect conditions obsolescence is inevitable.

7.3.1 Government role

This paper aims at establishing long-term goals, objectives, and ways to assess the replacement of building stock, and the consequences deriving from its implementation could be further potentialized by government intervention.

Design Requirements

As one of the potential improvements for long-term thinking the government may include within the permitting process the requirement of new designs documentation that force to establish a sustainability baseline for the building envisioned.

To put it simply, returning back to the first cornerstone of the thesis. The result presented there envisioned the ex-ante forecasted results for a house cumulative energy. The idea is that every building asset has its own curve so that real estate companies when acquiring new stock can potentially determine re-development possibilities without incurring sustainable impacts.

This can be further improved by introducing also the cumulative carbon curve, so that the whole end to end process is accounted for:

$$Cumulative\ Carbon\ = Initial\ EE + Recurrent\ (Operations + Embodied\ Renovations)$$

Subsidies to counter Gentrification

Given that it was proven that demolition would end in not only more profits, but also less carbon emissions, it is in the best interest of the government to maximize this opportunities so that society can reap its benefits.

A potential research is proposed, given the results from below a Cost benefit analysis could be undertaken so as to demonstrate if subsidization of these type of projects would yield better results for the populations welfare on a long-term perspective.

The IRR presented for the inflation case at T=75 is roughly 8.5% and in reality, this might not seem so appealing to an investor, however if the government supports with subsidies investors could actually undertake these projects with a higher IRR and without incurring gentrification for the population.

This would mean that once the development has occurred, previous tenants could access the newer properties with the same or a relatively minor increase in property prices so that it is still appealing to them, and a utility curve trade off occurs.

Sustainable & Long Living Materials

Alternative or Parallelly the government could further impose negative externalities on industries that produce non sustainable materials and positive ones on sustainable producing materials.

An example of positive externality - Would be offering tax reductions in the investment in case of use of wood instead of concrete (at least in a given % since foundations require concrete), since it was mentioned during the literature review that the main structure frame possesses the highest impact to the environment.

7.3.2 Engineering & Design Role

Engineering efforts should aim to focus on continuous materials improvement, from their long-living characteristics while trying to dampen the cost to acquire them.

Engineering

As a short-term approach to the cumulative energy curve for the first cornerstone, let us remember that this was done for a house. While ideally, we would have a tailored curve for each project, in reality it will take some time to materialize. As a solution to counter this, it is proposed to employ studies on standardized asset classes with standardized heights. The result of such studies should aim to help in sustainable demolitions decisions, an example would be:

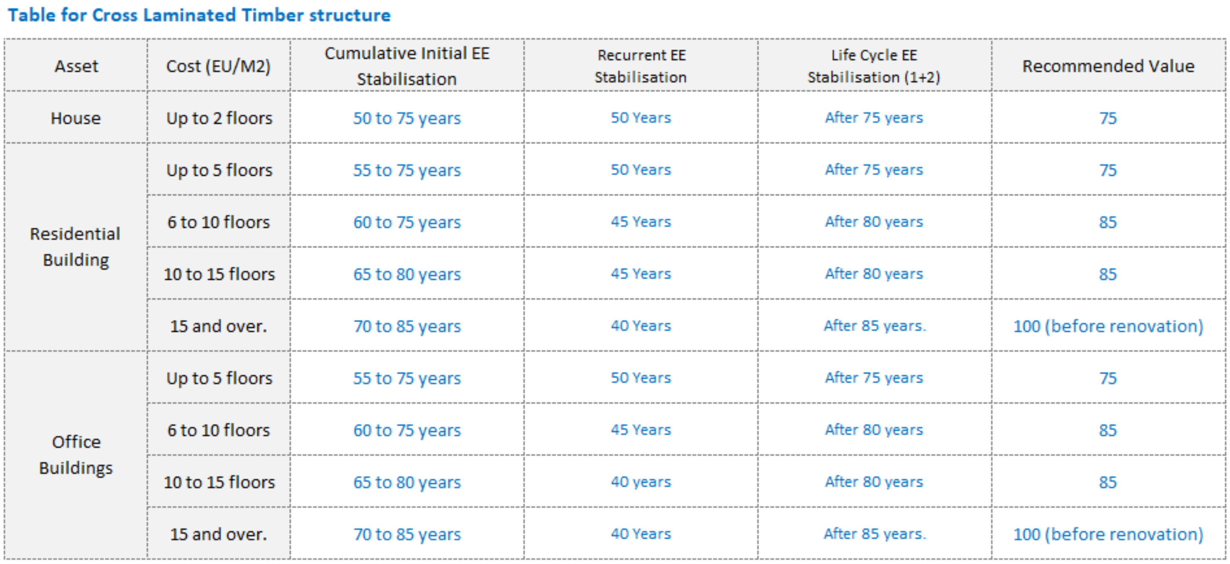


Table for Cross Laminated Timber structure

Asset	Cost (EU/M2)	Cumulative Initial EE Stabilisation	Recurrent EE Stabilisation	Life Cycle EE Stabilisation (1+2)	Recommended Value
House	Up to 2 floors	50 to 75 years	50 Years	After 75 years	75
Residential Building	Up to 5 floors	55 to 75 years	50 Years	After 75 years	75
	6 to 10 floors	60 to 75 years	45 Years	After 80 years	85
	10 to 15 floors	65 to 80 years	45 Years	After 80 years	85
	15 and over.	70 to 85 years	40 Years	After 85 years.	100 (before renovation)
Office Buildings	Up to 5 floors	55 to 75 years	50 Years	After 75 years	75
	6 to 10 floors	60 to 75 years	45 Years	After 80 years	85
	10 to 15 floors	65 to 80 years	40 years	After 80 years	85
	15 and over.	70 to 85 years	40 Years	After 85 years.	100 (before renovation)

Table 17 - Proposal for Cumulative EE solution for sustainable restrictions. Source: Own work

The values shown on the table are illustrative and do not convey at all a scientific study performed.

Design

Projects from an ex-ante perspective should envision a long-term cumulative emissions curve given the service life of each component used in the design. The investor can utilize these output and monetize it in terms of cumulative costs over time so objective decisions can be made.

7.3.3 Circularity

Circularity envisions to improve a supply chain through the implementation of post-use retaining value techniques, such as re-using, refurbishing, remanufacturing and recycling. Its objective is that society itself becomes sustainable by finding ways to implement it in diverse industries.

While circularity can be applied to diverse aspects of real estate, here only the demolition event will be addressed. Since it has been proven that through demolition, we could actually improve the GHG emissions and cumulative energy, now a more interesting questions arises ¿What do we do with the old building? This is where we can leverage ongoing researches and projects that address this, so that in the long-term strategy everything is integrated. As an example:

- Re-using & Refurbishing: Could envision the transport of old building components into other buildings which are older, as an example: If a 1980 building were to be replaced, we could in theory re-use components on buildings of less age (e.g., 1970) and generating a net improvement. Alternatively worn-out components could be refurbished on renovations to be performed. This is one of the examples of deconstruction.

This is an area that has yet to be further developed and it has still immense opportunities to address.

7.3.4 Cultural Heritage - ¿What does the future look like?

Cultural Heritage holds a special place in this thesis, since it must be acknowledged that there exist real estate assets whose value is intangible and represents an important restriction that this model cannot account for.

Moreover, cultural heritage does not only apply to assets as a whole (e.g. Roman Colosseum) but also comprises architectural, construction and historical characteristics which form part of the cultural heritage of different epochs. As a matter of fact, cultural heritage is dynamic, and it evolves with time. Eventually in 500 years, the innovations and real estate of today will become the cultural heritage of tomorrow.

However, the prior engenders an important question from a Real Estate point of interest. ¿How can we selectively retain the cultural heritage without hindering infrastructure and technological progresses as a society? This is something that must be discussed in greater detail.

As we have seen in the case study, sustainable and financial feasibility for an asset demolition and replacement occurs after 75 years, furthermore this replacement is not only known to be cost-effective, but also to bring benefits to its users in terms of comfort, spaces distribution, technology, and current living practices which account the social facet.

Thus a contradiction is born, on one side it is known that we must preserve cultural heritage, and on the other we know that as society evolves it brings with it benefits stemming from new developments.

7.3.5 Selective and Flexible Listing

The proposal of inclusion of the social aspect to demolition may be incorporated through the enhancing of selective and flexible listing. That is, proposing additional guidelines to the built environment under which the developers and the society has wider flexibility on how to approach infrastructure evolution.

Some countries are known to have imposed strict guidelines on when a building is listed, basing the decisions according to the buildings age (even if it has not matured from a demolition perspective e.g., T=75), on other cases the listing is more flexible and allows more considerations to take place however the final decisions still not account for future developments. Some other countries on contrast, have no established guidelines defining when a building must be listed, which in many cases lead to demolitions that have an impact on their built cultural heritage.

The vision is that in the future, when evaluating listing decisions (including currently listed projects) there is a risk evaluation process that analyses each type of replacement that may occur and assesses if whether the impact stemming from its development would inherently affect the cultural heritage of the asset. This would present a quali-quantitative approach that can further integrate with the current model if the asset in question is listed in some degree.

Figure 35 – Built environment Differences after demolition. Source: Own work created with Krea Artificial Intelligence

Figure 35 – Built environment Differences after demolition. Source: Own work created with Krea Artificial Intelligenceshows an example of the ideal state an asset and its built environment would change according to flexible listing. The general assumption for flexible listing in this example comprises façade architecture to ensure cultural heritage preservation.

In this example, the initial photo (left) was generated by artificial intelligence showing a residential street in an Italian metropolis. Then the AI was asked to change built environment characteristics so that it represents actual and future infrastructure characteristics while keeping the buildings the same (right). While it is not perfect, the idea would have been to show the same facades.

The objective of this example, is to show that even if the buildings are completely different on the inside and the outside environment changed, the distinctive façade architecture which is noticeable in Europe remains present, thus we can evolve as a society while keeping important remnants of the culture. In other words, the mindset when talking about demolition is not necessarily to think about big developments or skyscrapers that blur out the rest, but to assess and analyze objectively how can we do it in a sustainable way and that it engenders benefits for society.

7.3.6 Community Driven design books for listed

In the cases where demolition decisions are undertaken a further step can be taken by engaging actively with the community so that the project is conceived from a social perspective by not affecting cultural heritage values.

This could be done through the implementation of stated preferences techniques by the usage of choice modellings which show different alternatives that address different cultural heritage attributes, while keeping in each alternative values that private developers require for their projects to be feasible.

The choice modelling would not only reveal which is the most preferred option among actors in the community, but it would also reveal which attributes do they value the most and if any of the options is attractive. This could engender new project ideas that highlight this that envisions asset replacements while optimizing the community utility and welfare.

8. ADVANTAGES & SHORTCOMINGS

8.1 SHORTCOMINGS

While the model proves as a useful tool, it has to be acknowledged which limitations and assumptions it considers in order to have an adequate assessment and know possible improvements. Among these shortcomings we have the following:

- Measuring the benefits engendered through the social improvements following a replacement are not considered. For example, user comfort or satisfying user needs.
- The thesis cornerstones are vital, however in reality they should be merged as one. That is a single study that accounts for all cumulative costs incurred from an energy point of view. As mentioned in earlier sections, a formula was proposed to account for this.
- As mentioned in the first cornerstone, the values proposed correspond to residential housing with a mix of timber, concrete and brick. It does not strictly correlate to other type of buildings, thus a study for different typologies must be performed. As mentioned in previous chapters this study could propose a standardization by asset class and height as a first short-term measure.
- Ideally each project should have its own assessment of the cumulative energy curve, so that the decision takers can integrate it with financial information.
- The model proposed takes only into account endogenous factors that affect the project during its lifetime, it does not comprise externalities that may affect it positively or negatively. As an example, during the second thesis cornerstone paper, it was mentioned that the researcher initially envisioned an energy improvement coming from the network.
- The thesis directly addresses the ‘what’, ‘where’, ‘when’ and ‘why’ of demolition but it does not address the ‘how’. During the discussion it is mentioned that the latter plays an immense role in achieving sustainability not only from an environmental point of view but also social.
- In accordance to the prior shortcoming, it is worth mentioning that even if we were to implement deconstructing methodologies or new processes for demolition, there still would be demolition residues which have an impact in the downstream supply chain, for example landfills.
- The thesis acknowledges there exists additional social impacts stemming through demolition redevelopments, such as gentrification. And while it mentions a possibility to offer status quo possibility, after such an event it does not offer theoretical research supporting this.
- In order to implement this model, it requires a considerable amount of information recollected during a significant time frame (in the human perspective), which on buildings dating back to 1970 is often the case where it is hard to acquire. Furthermore, in current developments it is not always the case where the owner does a proper tracking of all of these datapoints which would latter prove difficult to acquire, and even when real estate transactions occur the historic information of the asset is not always available.
- From the utilities point of view, this model only accounts for energy improvements on an ‘apartment basis’, however from a owner point of view, there could be much more efficiencies from improving the overall building network including MEP.

- Maintenance costs and renovation are non-linear, and even when doing specific assessments for every project these will vary over the course of their implementation. A simple solution would be to forecast assuming constant costs over the years, and when it would be necessary to implement important renovations to assess the decisions.
- As mentioned earlier the OPEX table is project specific and has to be tailored for all current design and future proposals. If a project proposes more than 1 design alternative it should be also accounted for as a different curve.
- The current cashflows are subject to the inflation assumption, which in reality is non-linear and can be considered stochastic, thus risk methodologies must be implemented to assess their changes. Nevertheless, it was proven that given a model with no inflation the values are much more critical compared to inflation ones.
- The current cashflows carry over many limitations that are engendered with PV, DCF and IRR. For example, it does not take into account the leverage required to endeavor such new developments.
- While it is mentioned in the case study that the owner has been the same, this is not likely the case in real scenarios, as investments in real estate have maturity periods. While this engenders some new considerations in the cumulative costs curve, for example the investment when buying an old building already developed; It should not prove difficult to incorporate the continuum of the curve assuming that costs incurred prior to transaction did not occur.
- One of the core assumptions is the improvement of engineering, technology and materials over time, and if these were not to happen in a significant way or at all over a long-time period it would result in a non-demolition decision or rather non feasibility. Although in reality this has been proven to be not true, since most of European stock has this potential.
- The case study assumes that an IRR of circa 8.5% for an investor is appealing, while in reality it is low given that the investment could be considered a brownfield. It is yet to be proposed an improvement on how to keep prices stable after a re-development to ensure also social sustainability.
- The thesis acknowledges the 3 facets of sustainability, but it is straightforward that the social aspect is hard to measure mathematically, and even if accounted for subjectively it has different layers and categories to be accounted for, this is an improvement area.

8.2 ADVANTAGES

- The initial hypothesis envisioned was proved by the model.
- The model accounts the financial facet, where it demonstrates that cost savings over a long period can offset initial investments even with discounted values.
- In addition, it can integrate different types of projects and redevelopments which may occur during its lifetime, having an overview of the asset's economic performance and data.

- Environmental sustainability is possible to be incorporated to the model, albeit in its initial stages, it shows promising results which conclude that in the long-term horizon the assets reach a ‘stabilized’ stage where cumulative preservation offsets or is similar to a redevelopment.
- Social sustainability, while addressed at a high level, proposes an outline of critical topics that must be assessed along with possible solutions. Considering these along with the literature review and its reference it could be possible to build a more robust framework for social facet to be considered.

9. CONCLUSION

This thesis presents the initial steps which support in determining demolition necessity in the form of a deviation or derogation from the current trend of thought that the majority of the community is employing in their researches.

It aimed to acknowledge that while environmental solutions are imperative and must be undertaken given our current climate change problematic, we should not shift entirely our efforts on one side of the impacts as a reactive measure; Instead, it envisions understanding how the necessity to demolish can start to be integrated from the Environmental, Financial and Social facets so that the end product results in an objective decision that further benefits society.

What is proposed in this paper aims for a long-term strategy, in which through careful planning we can assess ex-ante, during and ex-post the project the demolition criteria to be considered. As it happens in the maintenance world, a component can only be maintained for so long before due to obsolescence or its life has to be replaced; It aims at combining renovations with building replacement, the former being a short-term solution and the latter a long-term one.

In the end, it was proven that it is possible to account for financial viability thanks to improved performances deriving from engineering, materials and technology optimizations over the years, without the necessity to do bigger developments. It was also demonstrated that by including a complete energy assessment of the building components and performance, it is possible to determine a constant or ‘stabilized’ state, where energy cumulative results over a long horizon hold the same between constant asset preservation or demolition. Finally, it outlines a series of social sustainability layers that must be expanded and further dived deep into if we want to achieve a complete ESG integration.

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"In most cases, the less math is involved in a discussion, the more prone the topic is to be subject to interpretations and political involvement."

12. CREATIVE COMMONS

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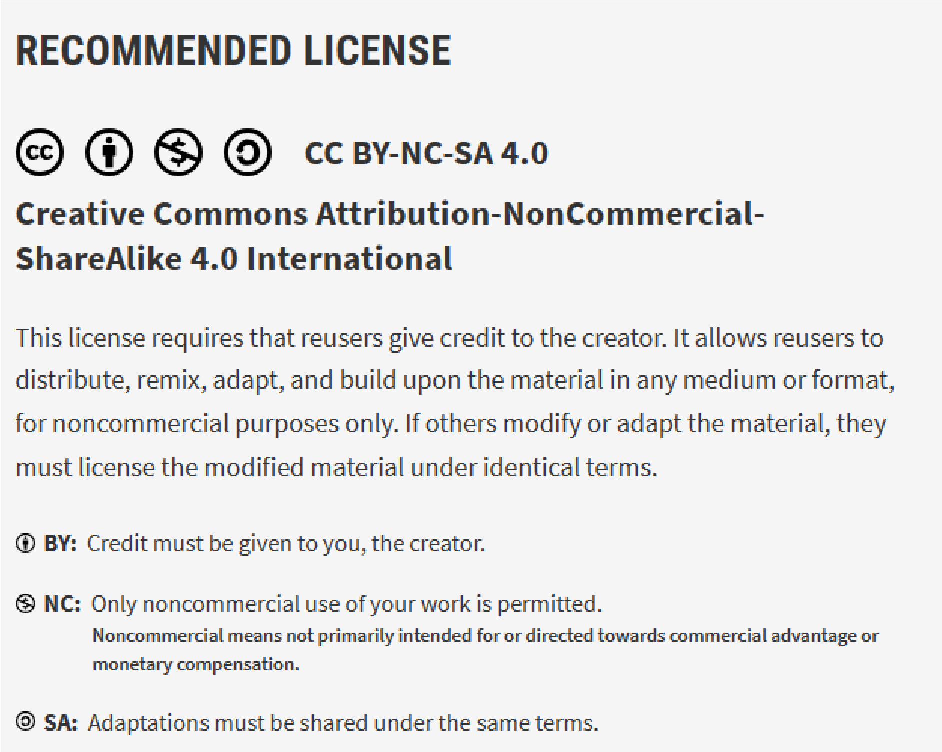

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