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Master in

Building Information Modelling



European Master in
Building Information Modelling

Life Cycle Assessment through BIM-based advanced Calculation
Virtual Environment Workflows

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“People don’t buy what you do; they buy why you do it.”

Simon Synek

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SOMMARIO

Valutazione del ciclo di vita attraverso i flussi di lavoro dell'ambiente virtuale di calcolo avanzato basato sul BIM

Il settore globale delle costruzioni affronta la necessità di adattarsi al cambiamento climatico e allo stesso tempo di spostare l'industria verso la decarbonizzazione, diminuendo l'uso di energia negli edifici al fine di rispettare le normative internazionali. Ogni paese che ha sottoscritto l'Accordo di Parigi è tenuto a stabilire obiettivi di riduzione del consumo energetico e delle emissioni di carbonio in base alla propria realtà economica.

I materiali da costruzione che mirano al risparmio energetico, il consumo di elettricità e l'emissione di carbonio sono profondamente connessi perché uno può essere responsabile dell'aumento dei due precedenti. I materiali da costruzione sono la fonte di emissione di carbonio più alta, dato che gli sforzi per passare alle energie rinnovabili sono già una realtà. Questa conclusione getta luce sulle soluzioni che possiamo già implementare per evitare le emissioni dovute ai materiali da costruzione prima che assumano il titolo di maggior voce di emissione. Anche i materiali da costruzione sono ovunque, negli edifici esistenti, non solo nei cantieri in corso. Sono gli edifici esistenti ovunque, la maggior parte dei quali fuori uso, pieni di potenziale ma energeticamente inefficienti. Restaurando gli edifici esistenti permettiamo il mantenimento della memoria, il riutilizzo delle strutture, la conservazione della loro massa costruttiva attraverso il suo reimpiego. Restaurare significa evitare la demolizione di potenziali beni utili, la produzione di rifiuti e il loro riempimento del suolo, e tutte le emissioni di carbonio legate alla produzione dei materiali da costruzione.

Questa espone il potenziale dell'implementazione del Building Information Modelling per la ristrutturazione di edifici esistenti, concentrandosi sugli sforzi e le strategie di risparmio energetico, incentrati sulla selezione dei materiali e sulle loro prestazioni, con l'obiettivo di ridurre al minimo il consumo energetico dell'edificio e di diminuire considerevolmente le emissioni di carbonio, calcolate attraverso il Life Cycle Assessment. Un flusso di lavoro è un processo che inizia con lo sviluppo di un BIM di un edificio esistente simulando le sue condizioni e calcolando quale sarebbe il consumo energetico attuale. Il modello viene sottoposto a una simulazione delle prestazioni energetiche per capire quali aree sono più strategiche per l'intervento. I risultati della simulazione sono imputati in uno strumento di calcolo LCA basato su cloud per calcolare le emissioni di carbonio incorporate. Il BIM è stato sviluppato in fasi, passando attraverso lo stesso processo una volta inclusi i materiali di isolamento sui componenti dell'involucro da ristrutturare. I materiali saranno scelti dal database delle Dichiarazioni Ambientali di Prodotto. I dati generati saranno, ancora una volta, imputati nel software di terze parti per valutare la riduzione o l'eliminazione delle emissioni relative all'mantenimento del carbonio incorporato e l'impatto dei materiali necessari per soddisfare gli obiettivi di energia e emissioni di carbonio descritti prima. I parametri saranno realizzati per operare un confronto prestazionale.

Parole chiave: Building Information Modelling, Calcolo Ambienti Virtuali di Calcolo, Edificio a energia quasi zero, Prestazioni energetiche, Valutazione del ciclo di vita

ABSTRACT

Life Cycle Assessment through BIM-based advanced Calculation Virtual Environment Workflows

The global construction sector face the need of adapting to climate change and at the same time to shift the industry towards decarbonisation, decreasing the energy use in buildings in order to comply to international regulations. Every country that undersigned the Paris Agreement is expected to stablish decreasing goals for energy consumption and carbon emission according to their economic reality.

Construction materials aiming energy saving, electricity consumption and carbon emission are deeply connected because one can be accounted for the increase of the previous two. Constructions materials are held to be the higher title of carbon emission source since the efforts for shifting to renewables is already a reality. That conclusion throws light over solutions we can already implement in order to avoid emissions from construction materials before it assumes the title of higher impact sector. Also construction materials are everywhere, in existing buildings, not only in construction sites. They are the existing buildings everywhere, most of them out of use, full of potential but energy inefficient. By restoring existing buildings we allow the maintenance of memory, reuse structures, safekeep their construction mass by repurposing it. To restore means to avoid demolition of potential useful assets, waste generation and its soil filling, and all the carbon emission related to construction products production.

This research seeks to exposes the potential of Building Information Modelling implementation for refurbishment of existing buildings focused on the energy saving efforts and strategies, centered in material selection elected its performance aiming the lowest energy consumption by the building and by considerable decrease of carbon emission rates, calculated by Life Cycle Assessment.

A workflow is a process starting with the development of a BIM of an existing building simulating its conditions and calculating what would be the current energy consumption. The model undergoes an energy performance simulation to understand which areas are most strategic to go under renovation. The results of the simulation will be imputed in a cloud based LCA calculation tool to calculate its embodied carbon emissions. The BIM is developed in Phases, going through the same process once included insulation materials on the envelope components. The materials are chosen from Environmental Product Declaration database. The generated data are, again, imputed in the third party software to assess the reduction or avoidance of emissions related to the maintenance of the embodied carbon emissions and the impact of the materials needed to fulfil the energy and carbon goals described before. Parameters are created in order to compare their performances.

Keywords: Building Information Modelling, Calculation Virtual Environments, Energy Performance, Life Cycle Assessment, Nearly-Zero Energy Building

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This dissertation seeks to contribute to the following UN Sustainable Development Goals.

<p>3 GOOD HEALTH AND WELL-BEING</p> 	<p>The virtual development of buildings allow the simulation of living conditions and wellness for its users.</p>
<p>7 AFFORDABLE AND CLEAN ENERGY</p> 	<p>One of the goals is to evaluate the amount of energy needed after implementing passive strategies to an existing building, and demonstrate the renewable generation potential to power an asset.</p>
<p>8 DECENT WORK AND ECONOMIC GROWTH</p> 	<p>The construction sector is essential for the society's development and include tools for general improvement of the industry's workflow increasing its value chain.</p>
<p>9 INDUSTRY, INNOVATION AND INFRASTRUCTURE</p> 	<p>BIM export several file types providing better communication between teams, improving collaborative work and data sharing and bringing innovation the sector.</p>
<p>11 SUSTAINABLE CITIES AND COMMUNITIES</p> 	<p>BIM implementation for design and construction by the means of simulation and amplifies practices towards the responsible use of resources.</p>
<p>12 RESPONSIBLE CONSUMPTION AND PRODUCTION</p> 	<p>BIM implementation allows the generation of schedules and bill of quantities related to needed resources and predicting consumption rates. Manufacturers adapt to BIM implementation when develop their own data-enriched products.</p>
<p>13 CLIMATE ACTION</p> 	<p>The environmental impact of the construction sector tend to decrease by implementing BIM based strategies and calculation methods to limit carbon emissions rates.</p>
<p>15 LIFE ON LAND</p> 	<p>To renovate buildings aiming general efficiency includes the implementation of general resources saving strategies extending improvements to the outside of the building.</p>
<p>17 PARTNERSHIPS FOR THE GOALS</p> 	<p>The development of BIM connects stakeholder's needs to service provider's solutions generating innovative business scenarios.</p>

1. INTRODUCTION

The European Union (EU) launched in 2016 the European Green Deal (EGD), the block's action roadmap towards decarbonisation until 2050. The new regulations impact all sectors and aim to reduce carbon emissions by 55% by 2030, compared to 1990 levels. The impact on the architecture, engineering, and construction (AEC) sector focus on the construction of new buildings, and adaptation of existing ones both aligned to the concept of Zero Energy Buildings (ZEB), high-energy efficient buildings, with a low energy consumption need, using passive and active construction strategies to achieve them. The energy demand should be acquired from renewable sources generated – ideally – on site.

The Building Information Modelling (BIM) tools use for the development of new assets increases daily due to their simulation potential regards elements behaviour before construction providing a holistic view and predicting the cost of construction from design concept until handover to the client. They provide communication and sharing methods between all professionals related to the design phase allowing structured, data-oriented, with a clear workflow, avoiding errors, saving time and money on the process. The BIM implementation is most common to occur during the conception phase of new buildings when shape and orientation are not constraints and the building performance has a level of expectation according to firmed contracts and the project's BIM Execution Plan (BEP).

On the other hand, the freedom and experimentation provided by BIM when dealing with existing buildings are limited due to restrictions like shape and orientation. In addition, building performance tends to be inefficient due to general conditions of materials, considerably costly for maintenance and improvement, condemn to ruins and finally demolished. The recovery of an existing building represents the environmental responsibility of the sector, avoiding construction waste generation and by extending its life, becoming a business opportunity and a social solution, and achieving European Green Deal's (EGD) strategy to carbon emissions avoidance.

The requirements in construction nowadays – financial cost, environmental cost, and indoor quality - are harder to achieve when the building is already standing because it does not share the same built quality of a new one due to materials decay and decreased efficiency with time. The BIM provides the needed simulation tools for evaluating the benefits of recovering them. The use of BIM to qualify existing building conditions by acquired data and simulate ongoing life expectancy becomes a strategy to meet the current global needs of reducing the environmental impact of Greenhouse Gases (GHG) released by the construction sector.

The BIM technology and its interoperable tools allow connecting data related to the energy consumption and carbon emission rates by imputing those into calculation virtual environments developed to help the sector achieving those goals. The generated graphical results allow all stakeholders to evaluate impacts and make conscious decisions based on data. Using Calculation Virtual Environments to check alternatives and their impact saves time by easy update procedures and generate reports for several purposes including Certification and Labelling.

The structure of this research seeks to understand the AEC sector's status related to the energy use of existing buildings according to their conditions, simulate energy improvement with BIM tools, and using these data to predict the environmental impact, focused on material performance for refurbishment works. The research considers that the existing built stock is maintained as it is, and the energy saving is perceived after the inclusion of different insulation types compared, then by their performance levels and environmental footprint.

Chapter 2 focus on energy sector particularities highlights and discuss why the renewable shifting is so important to achieve the EGD goals. It introduces the different concepts of ZEB's, their implementation and considers Italy's national definitions of the ZEBs demonstrating the national requirements related to building performance.

Chapter 3 focuses on the construction materials that compose a building envelope, its properties and ways of calculating them. It demonstrates the complex calculations needed for the virtual simulation of an existing envelope.

Chapter 4 introduces the BIM technology, modelling strategies towards data acquiring, strategies for creating and sharing data between teams, and the impact of this development for Operations and Management of an existing building.

Chapter 5 introduces the Life Cycle Assessment (LCA) the analysis of environmental impact during the whole life cycle of a building. The research makes use of the Environmental Product Declaration (EPD) and describes the advantages and ways to use its data source for the LCA process.

Chapter 6 introduces calculation virtual environments developed to fasten data generation and processing for BIM-based use.

Finally, chapter 7 demonstrates a workflow for LCA based on a BIM. The chosen BIM uses Autodesk Revit 2021 as an authoring tool. The model uses the Phase tool and the initial hosts the As-Is model. The following phase has insulation layers, which makes the energy consumption value decrease and is calculated using Green Building Studio. The creation of insulation family types use basic visual programming with Dynamo scripts, their parameters values relies on EPD's and Machine Readable EPDs. The reason for modelling the new types with their specific technical values lies in the need for their geometric information to transfer into the calculation as materials quantification. The model's geometrical data, together with its calculated energy rates for each created material is included in LCA Calculation Virtual Environment (CVE) called ONE CLICK LCA®. It calculates the environmental impact for both existing and improved conditions. The process demonstrates how strategic BIM can be to study options for energy improvement.

2. ENERGY MARKET FRAMEWORK IN EUROPEAN UNION

European Union is a complex structure composed of multiple institutions and agencies focused on essential services that regulate the block's market. The European Union Agency for Cooperation of Energy Regulators (ACER) is the EU agency for the energy market, established in 2011 as an independent legal entity between the Member States and EU to support policies implementation and make decisions technically and scientifically based. The importance of the agency is to ensure the integration between the EU's energy policies and regulatory frameworks. Once the regulations are approved State Members are urged to develop their plans according to their reality whose impact cannot be lower than the EU regulations.

2.1. Energy production sources and CO₂ emissions in Europe

The energy production in Europe comes from multiple sources, mainly non-renewable and is CO₂ highly emissive. Its locally production and import makes the energy price vary between countries.

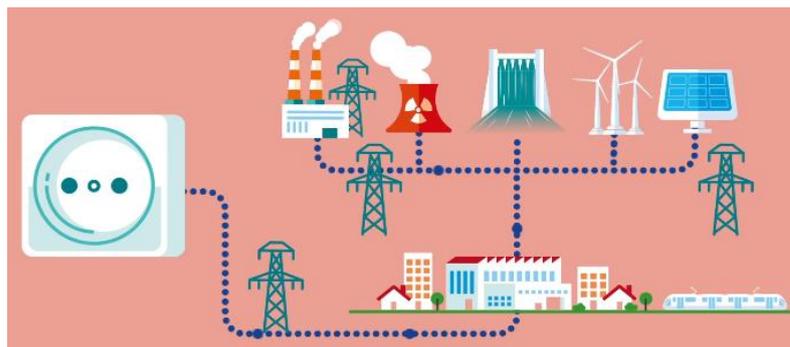


Figure 1 – Energy production from source to switch. (Eurostat)

According to US Environmental Protection Agency (EPA), Greenhouse Gas (GHG) traps heat in the atmosphere and its high rates can be associated with energy production sources. These gases combined refers to as Global Warming Potential (GWP) gases. They are:

- Carbon Dioxide (CO₂), released by burning fossil fuels, solid waste, trees, and biological material. It can be removed from the atmosphere by plants as part of the carbon cycle; Regenerative design can play an important role by including proper vegetation in projects, which can be measured to anticipate absorbance potential;
- Methane (CH₄), released during production and transport of coal, natural gas, and oil;
- Nitrous Oxide (N₂O), emitted during industrial activities, combustion of fossil fuels, solid waste, and wastewater treatment;
- Fluorinated gases, which are synthetic powerful gases emitted in smaller quantities.

According to International Energy Agency (IEA), electricity generation is the most emissive sector answering for more than 40% in 2018. Industrial, residential and public services are the sectors with the highest consumption and growing.

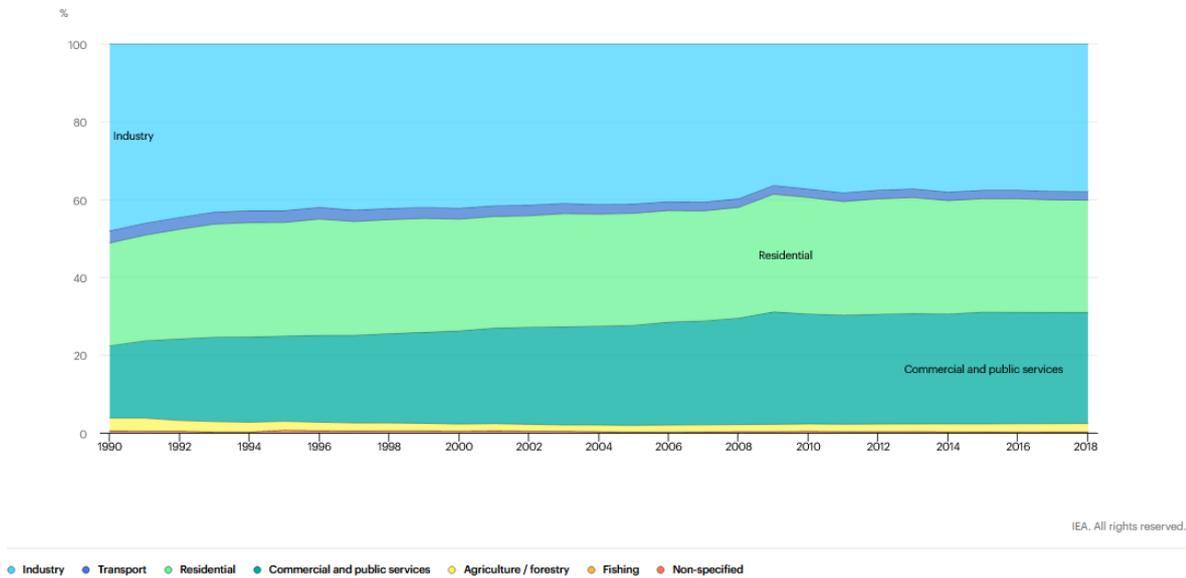


Figure 2– Electricity final consumption by sector, Europe 1990-2018 (IEA)

Shifting to renewables sources tends to decrease the monthly cost of energy for users and CO₂ emissions related to the energy generation process. The installment of solar panels increases yearly since the beginning of 2000, mostly by individual consumers encouraged by government fiscal incentives, and the diversity of products available. The advantages of autonomous electricity production are the decrease of energy bills, reaching zero depending on the equipment’s performance, it may contribute to the network when production is higher than consumption and is considered a stable source of energy. Buildings whose generation is higher than consumption are known as Positive Energy Buildings (PEB).

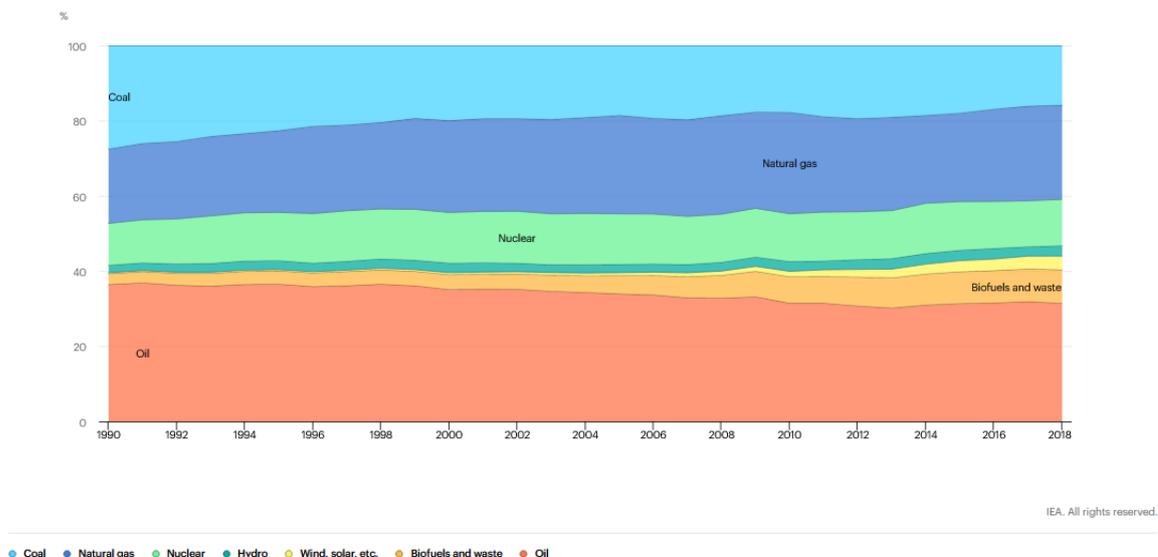


Figure 3 – Total energy supply by source, Europe 1990-2018 (IEA)

2.2. The European Green Deal aiming carbon neutrality

Carbon emissions are the worst product of human activity and are directly responsible for our decreasing atmosphere protection layer setting humanity to our most urgent unsolved problem: the global Climate Crisis. The climate reality depicts the need for general resilience and adaptation throughout sectors. By 2050 European Union aims to become the first climate-neutral continent and so launched in 2016 the European Green Deal. Becoming climate-neutral means reaching a balance between carbon emission rates from human activities and the atmosphere’s carbon-absorbing capability. Measures like passive strategies design for internal comfort and shifting the energy generation sources to renewables contribute to decreasing GHG emissions in the long term. The roadmap towards 2050 includes a middle way milestone, which is lowering carbon emission rates to at least 55% below 1990 levels until 2030 and becoming carbon neutral in 2050.

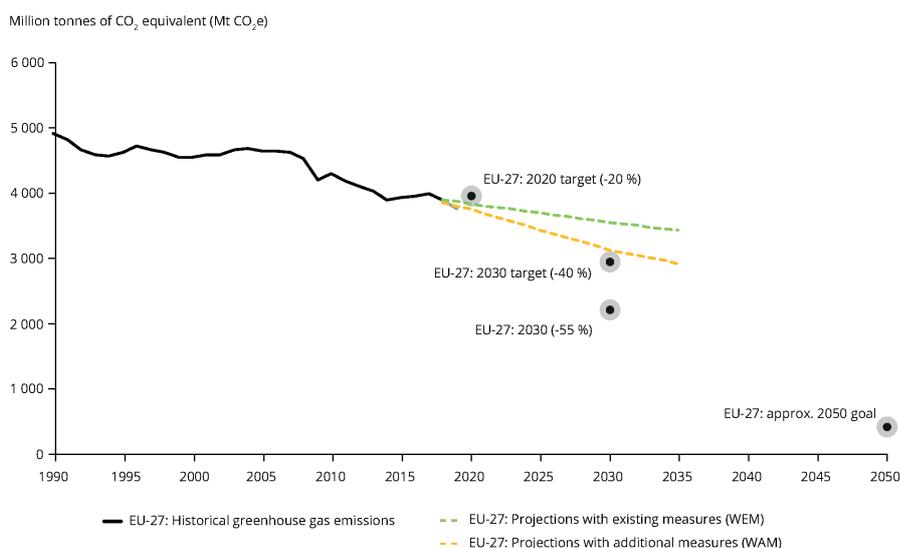


Figure 4 – GHG European Union Emissions targets for 2030 and 2050 (EEA)

2.3. The urban environment contribution

According to the UN World Urbanization Prospects, 68% of the population will be living in urban areas by 2050 depicting a harsh scenario of urban unfairness like housing and energy availability.

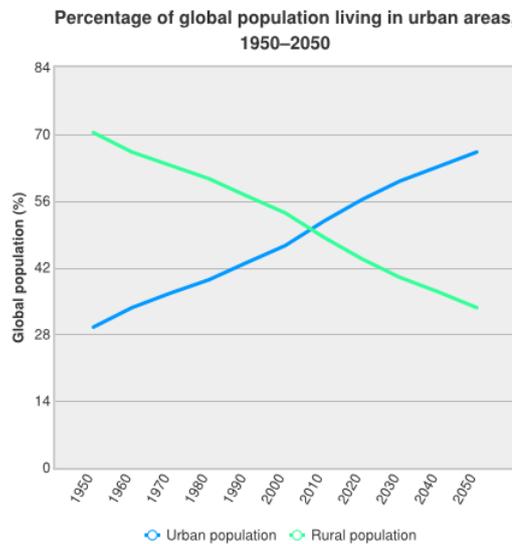
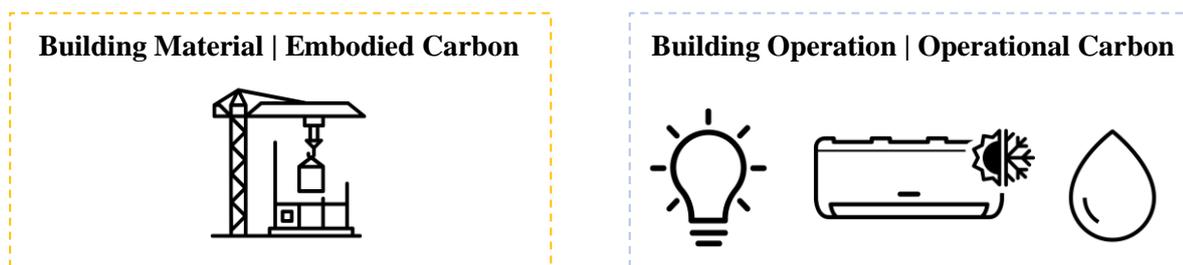


Figure 5 – World Urbanization Prospects: The 2014 Revision (United Nations)

Growing cities increase carbon emission into the atmosphere affecting our global thermal balance, creating weather instability and extreme climate-related events which we already face such as intense storms, flooding, heat and cold waves, seasons’ delay or extension, droughts, among others. Climate instability is a threat to life. It knows no borders and it affects all. Sustainability should be our global reference for survival because it provides a holistic view and connects the entire environmental energy cycle – air, water, carbon. It affects directly the planet’s natural resources as we know and use for human basic needs like agriculture, air quality, and water supply availability. The way to go is adaptability to changes and make our cities the most resilient as possible.

According to the UN, the AEC sector is responsible for 40% of global Greenhouse Gas (GHG) emissions: 11% for building construction materials (known as embodied carbon) and 28% for building operations (known as operational carbon), which includes electricity consumption, heating and cooling and use of water. Decreasing energy demand for the operational phase decrease emissions related to it.



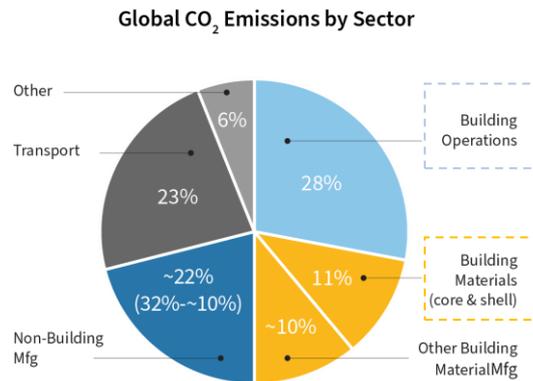


Figure 6 – Global CO₂ emissions by sector (Carbon Leadership Forum)

Following the events of UN’s Conference of the Parties (CMP) 21 that took place in Paris in 2015 and the official document known as Paris Agreement, 195 countries undersigned the global efforts for lowering CO₂ emission rates and agreed on the seventeen UN’s Sustainable Development Goals, which came into effect in January 1st. 2016. Nine out of seventeen UN Sustainable Development Goals (SDG) relate to the AEC sector, calls for action towards urban development, building construction, renovation, and energy usage, amplifying and demanding urgency for innovation, and creating business opportunities.



Figure 7 – WGBC inputs under UN’s Sustainable Development Goals into the AEC sector

2.4. European Performance of Buildings Directive (EPBD)

The Directive 2018/844/EU amending the 2010/31/EU known as the European Performance of Buildings Directive introduced the concept of Nearly-Zero Energy Building (NZEB). The European Green Deal establishes goals for different sectors, as for the AEC sector relates to definitions and

requirements for both new and existing buildings. New buildings and existing ones recovery process are expected to be data-oriented, allowing simulation of results for decision-making based on option that meets new requirements and expectations of stakeholders.

- One is building new assets guided by best practices seeking to neutralize carbon emission along the sector's consumption chain during the entire life cycle of the new asset;
- The other is to refurbish, renovate or retrofit existing buildings. Apart from the common expectations, this solution requires a deep study of the environmental and cost-benefit of the recovery process. The benefits of the process lie in the considerable decrease of energy consumption due to high-performance materials included in existing buildings and maintenance of building's Embodied Carbon, avoiding its demolition, waste generation, and the carbon emissions related to this process.

According to EU Commission, 75% of their building stock is energy inefficient and reports indicate renovation rates on the level of 1,2% a year. The building stock in Europe is old, with inefficient or none HVAC systems, high energy consumption, and energy loss rates due to natural worn material that composes the existing building envelope.

2.5. Renovation efforts and Built Stock in Europe

As part of the European Green Deal package, it was launched the [EU Building Stock Observatory](#), a database of EU-built stock depicting the renovation potential as a strategic tool for energy consumption reduction. All member states are responsible for the platform enrichment to increase transparency, providing reliable data for policymakers and construction sector stakeholders to a take responsible part in the block vision for 2050.

Renovating assets with energy efficiency goals in mind increase their value and provide a solution for another social problem, which is housing. Built stock in Europe represents a key strategy for decreasing CO₂ emission rates by renovating and insulating existing buildings avoiding its demolition and a high rate of CO₂ into the atmosphere and landfilling.

Recovering old buildings allows preserving historic constructions, reducing embodied carbon release by reducing solid construction waste, repurposing, and extending their useful life. According to Monticelli et. al, the construction of buildings and their operation have extensive direct and indirect impacts on the environment during the life cycle.

An existing building has its **Embodied Carbon (CO₂e)** value, the carbon emissions associated with the manufacturing, transportation, and installation of the building materials already placed. This value is acquired with a Life Cycle Assessment (LCA) and the results are reported as Global Warming Potential (GWP equivalent unit KgCO₂e). The importance of calculating the Embodied Carbon of the existing building allows assigning complementary materials that provide both the insulation and envelope recomposition needed with low emissive values, that lasts for a long time without the need of multi replacements, decreasing the Cost of Ownership.

2.6. The ZEBs – zero energy buildings

According to (Sartori, Napolitano and Voss, 2012), the concept of a ZEB is an energy-efficient building able to generate electricity, or other energy carriers, from renewable sources to compensate for its energy demand. The definition of nZEBs differs according to national target and the impact of the implementation of this kind of building needs to reach synergy with the grid and avoid the system stress.

(Lu *et al.*, 2019) defines the concept of ZEB/nZEB in two ways, “off-grid” and “on-grid”.

Off-Grid ZEB

According to (Lu *et al.*, 2019) the “off-grid” ZEB is also named “autonomous” and “stand-alone” building which can be defined as “Zero Stand Alone Buildings”. These buildings do not require connection to the grid, or only as a backup. Stand-alone buildings can autonomously supply themselves with energy, as they have the capacity to store energy for night time or wintertime use”. This approach also includes passive strategies for lowering energy consumption such as natural ventilation and control of sun incidence by natural ways such as vegetation.

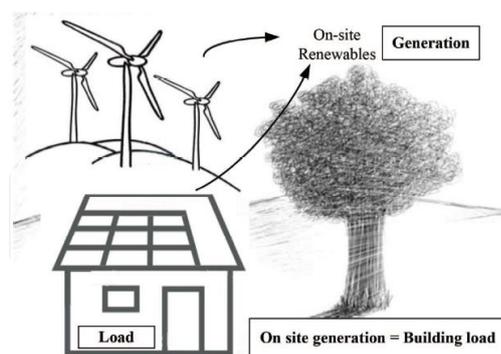


Figure 8 – Basic elements for the definition of an off-grid zero-energy building. (Lu et. al)

On-Grid ZEB

On the other hand, the “on-grid” ZEB, “grid-connected” or “grid-integrated”, the building connects to one or more energy infrastructure providers. It can be defined as “Zero Net Energy Buildings”. They are buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid” (Lu *et al.*, 2019). A high-efficiency building has the power to influence the existing energy grid becoming an energy provider known as **Energy Positive Buildings**, those that generate more energy than consumes.

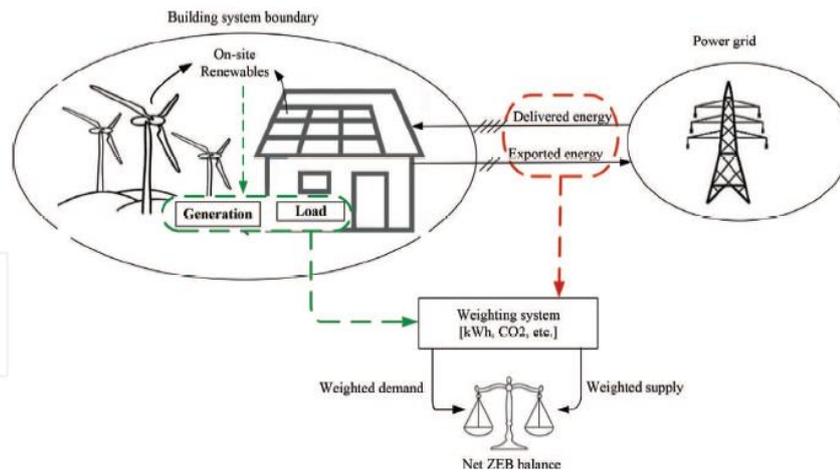


Figure 9 - Basic elements for the definition of on-grid net-zero energy building. (Lu et. al)

According to the Whole Building Design Guide, the **Net-Zero Energy Building** concept evolves daily but describes as a building that produces as much energy as it uses over a year. It combines building design to minimize energy requirements and renewable energy systems that meet reduce energy needs. They are also identified by having an energy utility bill of \$0 over a year.

Recovering existing buildings become an opportunity to repurpose the immense building stock available. The variables are many but the most impactful measures to address are the building envelope and energy generation methods. The envelope is responsible to protect inner space from heat loss and trap with the sole goal of keeping internal temperatures comfortable for the users. Existing buildings have a carbon emission-related value known as **Operation Carbon**, the amount of carbon emission related to the operational phase of the building by the use of electricity, water, heating, and cooling systems. The amount of CO₂ released during this phase relates mostly to heating and cooling intensity.

Replacing heating and cooling systems with renewable technological solutions such as solar panels and heaters, tiles and flexible layers cells, geothermal heat pump, combined heat and power, or photovoltaic are some of the currently accessible technologies available for all kinds of buildings. For the correct implementation of active energy generation systems, it becomes necessary to evaluate the existing asset conditions and consider possible solutions to reach the energy demand with a lower cost as possible.

Energy is not only electricity, the one used to perform daily tasks during the use of an asset. Energy is also related to the number of resources used to build up an asset, which can be calculated using the LCA method. According to De Wolf et. al, **embodied energy** is the amount of energy consumed, while **embodied CO₂e** is the amount of GHG emitted to produce a material, product or building. (De Wolf, Pomponi and Moncaster, 2017).

2.7. nZEB in Italy

Italy is one of the countries with an official nZEB definition stated in Law 90/2013. It defines a “**nearly zero energy building**” as a building characterized by a very high energy performance in

which the very low energy demand is significantly covered by renewable sources, produced within the building system boundaries”.

According to (Dall’O’ *et al.*, 2013), the methods to reach nearly-ZEBs are performing changes in envelopes raising the level of efficiency, exploiting renewable energy generation methods.

The need for renovation in Italy is imperative since, according to (Ezilda Costanzo *et al.*, 2018) energy demand for the construction sector in Italy represents 37,1% of the total.

Total Energy Demand - Italy

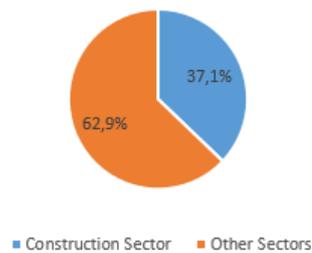


Figure 10 – Total energy demand. Personal graph based on data in (Ezilda Costanzo *et al.*, 2018)

As a country with diverse climate conditions, the envelope components need to be addressed with particularities since building performance changes according to local climate conditions. The Italian map is divided into five Climate Zones, each zone has performance requirements values slightly different, which have to be addressed as the only way to guarantee the efficiency of the envelope.

Le sei zone climatiche in Italia

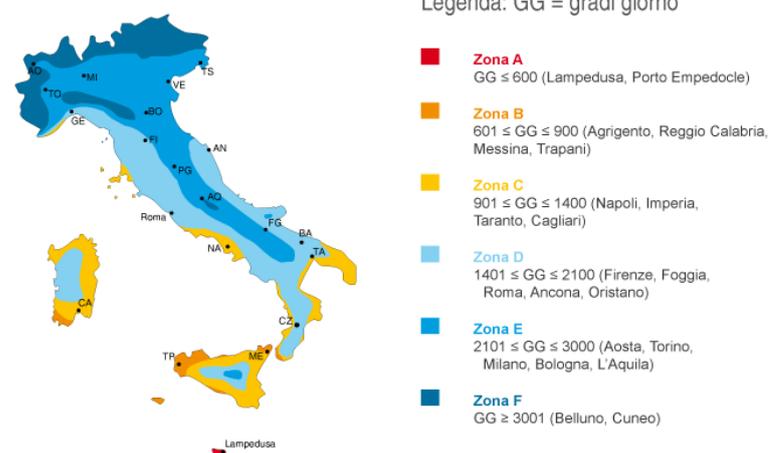


Figure 11 - Italy's climate zones map

According to (Ezilda Costanzo *et al.*, 2018) under the efforts for the development of EPBD Italy 2016, energy performance requirements for existing buildings are the same for residential and non-residential buildings. The minimum requirements differ based on the extension of renovation intervention, which can be:

- **Major renovation – first level:** defined as “refurbishment of at least 50% of the envelope and renovation of the heating and/or cooling plant of the entire building”;
- **Major renovations – second level:** defined as “refurbishment of at least 25% of the external surfaces of the building with or without renovation of the heating and/or cooling plant”. The U-value of the concerned surfaces is lower than the limit values seen in Figure 12.
- **Minor renovation:** defined as “refurbishment of less than 25% of the external surfaces of the building and/or modification of the heating and/or cooling plants.

Components	Validity period	Thermal transmittance U [W/m ² .K] (including thermal bridges)				
		Climatic Zone				
		A and B	C	D	E	F
Envelope – walls	From 2015	0.45	0.40	0.36	0.30	0.28
	From 2021	0.40	0.36	0.32	0.28	0.26
Envelope – roofs	From 2015	0.34	0.34	0.28	0.26	0.24
	From 2021	0.32	0.32	0.26	0.24	0.22
Envelope – floors	From 2015	0.48	0.42	0.36	0.31	0.30
	From 2021	0.42	0.38	0.32	0.29	0.28
Doors, windows and rolling shutter boxes	From 2015	3.20	2.40	2.10	1.90	1.70
	From 2021	3.00	2.00	1.80	1.40	1.00

Figure 12– U-Value limits for second-level Major Renovation and Minor Renovation (EPBD)

The inclusion of renewable energy source is a mandatory requirement for a building to be qualified as a nZEB. Again, this generation method covers the very low energy demand, produced within the building system boundaries.

The European Commission for Energy built up a data tool called “ZEBRA 2020” which focuses on tracking European market transition to Nearly-Zero Energy Buildings. The tool provides data and indicators to aid construction sector stakeholders during decision-making, separated by countries. Data acquired in ZEBRA demonstrates how Italian buildings are performing and labelled. Below shows the Heat transfer coefficient (U-values) identified in Italian buildings.

Table 1 - Building Energy Performance Related Values – ZEBRA - Italy

	Residential (85 units)	Non Residential (15 units)
Primary energy demand	15,9 kWh/m ² a	0,08 kWh/m ² a
Heating demand	17,6 kWh/m ² a	17,6 kWh/m ² a
Passive Energy Efficiency Solutions – Envelope Components		
Average U Wall-values	0,16W/m ² K	0,16W/m ² K

Average U Roof-values	0,16W/m ² K (wood fibers)	0,14W/m ² K (no insulation)
Avarage U Floor-values	0,19W/m ² K (no insulation)	0,17W/m ² K (no insulation)
Average U Window-values	1 W/m ² K (Triple Glazing)	1,1 W/m ² K (triple glazing 53%)

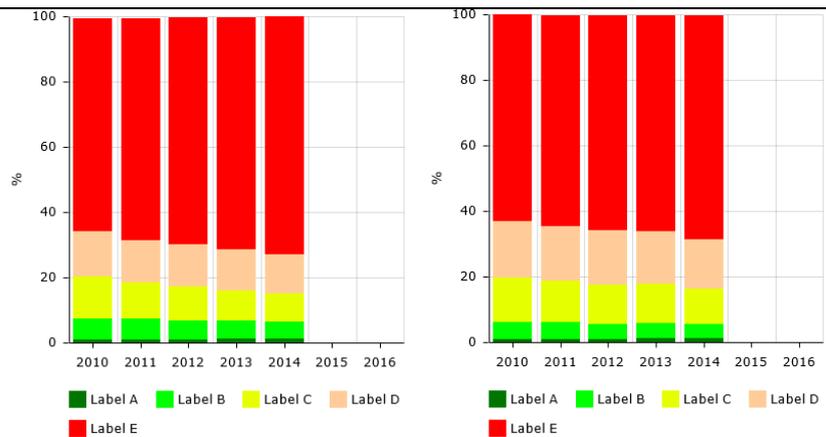
Active Energy Efficiency Solutions

Heating energy carrier (provider)	Electricity 44% , natural gas 21%, combined Heat and power 1%	Electricity 73% natural gas 13%
Mechanical Ventilation	Heat recovery efficiency 84%	Heat recovery efficiency: 100%

Use of Renewables

Photovoltaic panels	53%	60%
Solar Thermal systems	47%	33%

EPC Environmental Performances Certificates (until 2014)



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3. CONSTRUCTION MATERIALS AND ENERGY CONSUMPTION

As said before, understanding the existing conditions of the building is basic to define the level of insulation it needs to perform better and decrease the building energy consumption. The ways to acquire information of an existing building requires worksite visitation with specific tools and techniques to gather the maximum amount of information possible, which will be processed, calculated, and become valuable data. This investigation needs to be performed several times, under several weather conditions to reach an average result and understand the building's behavior. A building's material constitution research also allows the calculation of its embodied carbon, by the means of Life Cycle Assessment (LCA) and the cost of ownership known as Life Cycle Cost (LCC). The cost of ownership related to energy tends to follow the improvement of the building, identified by the decrease of energy bills, for example.

The surveys also allow understanding the surroundings impact on natural ventilation conditions, vegetation extent, and solar access, useful for the definition and placement of equipment to take advantage of renewable energy sources.

The Standard **UNI EN-ISO-6946:2018 Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods** – define the calculations method for thermal properties - resistance and thermal transmittance - of building components and building elements. It excludes doors, windows and glazed units, curtain walls, components that involve heat transfer to the ground, and components that allow air to permeate.

To comply with the requirements of the NZEB where the efforts for decreasing the energy consumption on buildings apply in Italy, the Heat Coefficient maximum values must not be higher than the ones defined according to climate zones.

To perform such a task on existing buildings it's imperative to understand the constitution of the asset and its properties. Construction materials have several properties, used for energy consumption simulation. The material's thermal properties are responsible for controlling thermal exchanges through the building's envelope.

Group	Properties
Physical	Shape, Size, Density, Specific Gravity etc.,
Mechanical	Strength, Elasticity, Plasticity, Hardness, Toughness, Ductility, Brittleness, Creep, Stiffness, Fatigue, Impact Strength etc.,
Thermal	Thermal conductivity, Thermal resistivity, Thermal capacity etc.,
Chemical	Corrosion resistance, Chemical composition, Acidity, Alkalinity etc.,
Optical	Colour, Light reflection, Light transmission etc.,
Acoustical	Sound absorption, Transmission and Reflection.
Physiochemical	Hygroscopicity, Shrinkage and Swell due to moisture changes



Figure 13 – Construction Material Properties table

3.1. Heat Transfer in a building

Heat transfer is the capacity of thermal exchange through matter from hotter to colder temperatures carried away by **conduction** (when materials are in contact), **convection** (when heat is carried by a moving fluid), and **radiation** (when heat is carried by electromagnetic waves from one area to another). All three methods are below.

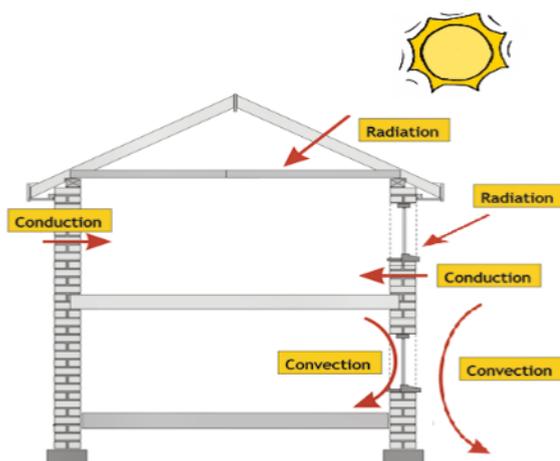


Figure 14 – Heat Transfer through a Building

3.1.1. Heat Conductivity (λ) value of a material [W/mK]

A material’s Heat Conductivity value is used for thermal calculations in buildings between materials. The Heat Conductivity unit is measured as [W/mK] and influences the value of Thermal Resistance

according to the material's width. The thicker the material, the higher is the material resistance (R). The equation for Heat Conductivity calculation follows:

$$\lambda = D/R$$

Where:

λ = material Heat Conductivity (W/mK)

D = material Width (m)

R = material thermal resistance (m²K/W)

3.1.2. Thermal Resistance (R-value) calculation: [m²K/W]

Thermal resistance is the measurement of a material's capacity to resist heat flow from one side to another, demonstrating the insulation effectiveness of a surface. The higher the number, the better insulation capability. The calculated metric unit for R-value is [m²*K/W]. The equations for calculating R-value are:

$$R = 1/U \quad \text{or} \quad R = D / \lambda \quad \text{or} \quad R = D / (A * \lambda)$$

The R-values of materials are additive meaning they sum themselves when attached. This composed R-value is the final resistance of an assembly. To reach the Heat Transfer Coefficient of the entire assembly, calculate with the following equations for U-value.

$$R_t = R_{si} + R_1 + R_2 + R_n \dots + R_{se}$$

Where:

R = thermal resistance (m²K/W)

U = material's heat transfer coefficient [W/(m²K)]

D = material Width (m)

λ = material Heat Conductivity (W/mK)

A = material area (m²)

R_t = total enclosure resistance

R_{si} = interior surface thermal resistance

R_{se} = exterior surface thermal resistance

R_{1,2,n} = thermal resistance of layers (calculated with R= D/ λ)

R_{si} R_{se} are calculated with the following equation:

$$\text{And } R_{si} = D_i / \lambda_i * A_i \quad \text{and} \quad R_{se} = D_e / \lambda_e * A_e$$

Where:

D_{i and e} = width of the surface of the most internal material and external material

$\lambda_{i and e}$ = Heat Conductivity (W/mK) of the most internal material and external material

A_{i and e} = material area (m²) of the most internal material and external material

The thermal resistance variables relationship can be seen below:

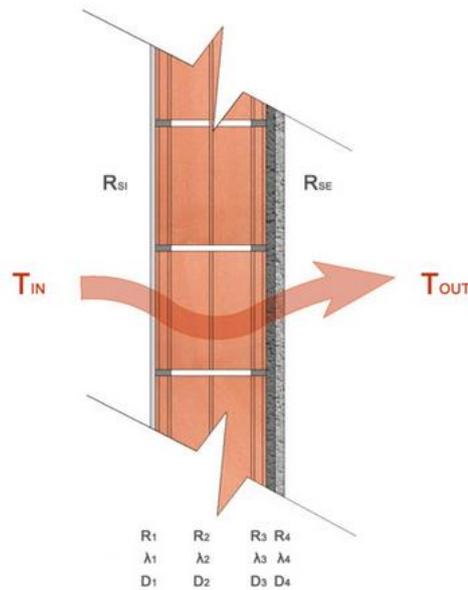


Figure 15 – Heat Transfer through a wall component

3.1.3. Heat Transfer Coefficient – (U-value) [W/(m²K)]

The U-value is the material's capacity to transfer heat across its width. This value is needed when refurbishing a building since the insulation material is added to the existing assembly, increasing thermal resistance. The power of computer simulation allows calculation of the effectiveness of a complementary thermal material as long as the existing one is reliable. The calculated metric unit for U-value is [W/(m²K)]. The equations for U-Value calculation follows:

$$U = 1 / (1/h_i + D/\lambda + 1/h_e) \quad \text{or} \quad U = 1/R_{\text{tot}} \quad \text{being} \quad R_{\text{tot}} = R_1 + R_2 + R_n$$

Where:

U = material's heat transfer coefficient [W/(m²K)]

h_i = internal face convective coefficient

D = material Width (m)

h_e = external face convective coefficient

R_{tot} = Sum of the material's resistances (m²K/W)

λ = material Heat Conductivity (W/mK)

When the R-value of the material is unknown, calculate it with the following equation:

$$U = \lambda / D$$

Where:

λ = material Heat Conductivity (W/mK)

D = material width (m)

4. BUILDING INFORMATION MODELLING – BIM

According to NBS, Building Information Modelling (BIM) is the process of creating information models containing graphical, non-graphical information and documentation in a Common Data Environment (CDE), a shared repository for digital project information. The data include becomes ever more detailed as a project progresses, is useful for all phases of a building life cycle turning the BIM into a repository and a reliable source for research of any aspect of the design.

The importance given to a building's data enrichment process allows using the same data, and any data originated by the previous one, to follow up the development of the asset according to the specified goal defined in the BIM Execution Plan (BEP). The BIM Execution Plan is the former document where parts agree on the performed services and the level of development of the BIM.

The BIM is used simultaneously by several people and for several goals. Communication between team members is sensitive and needed when working over the same model and for multiple purposes. Communication and file visualization is needed between and across teams members and follow standards to keep it organized and centralized. Communicating by using the model makes the process risk limited and straight to the point in terms of checking for inconsistencies. Exporting BIM files to IFC provides an easy way to visualize the file in multiple open BIM platforms, allow to communicate inconsistencies and clashes based on the model, and assigning responsibilities and deadlines. Bringing back the information of inconsistencies through a BCF file allows faster changes and an up-to-date model. This sequence of export-import works as a peer-to-peer managerial strategy suitable specifically for BIM-based models.

4.1. Communication methods between exported files

BIM models export a wide range of files, accessed in a wide range of platforms to perform different tasks. The model transfer is a common practice since BIM files tend to get larger easily, and the transference rate does not follow the industry's need. BIM files export the Industry Foundation Class files (IFC), for exchange and share information defined by the international standard ISO 16739:2018. These files are used broadly due to the ability of data transference due to its smaller size files, which can be accessed by many software. The IFC file can be used to verify clashes, check and search data inclusion, and they can be exported to BIM collaboration format (BCF), which can be opened in authoring tools like Revit to perform improvements signed using the IFC file.

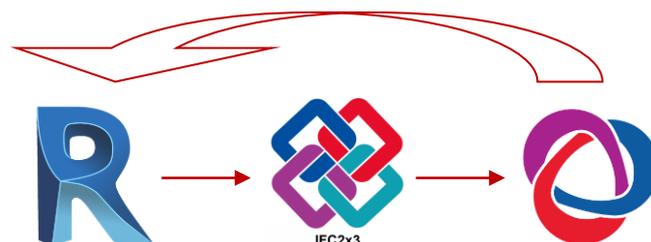


Figure 16 – BIM based communication sequence . RVT > .IFC > .BCF >.RVT

4.2. Computational Design – Dynamo

The uses of Computational Design while developing a BIM is avoiding repetitive work with the aid of scripts. In this research, Dynamo is used to generate Schedules in Revit.

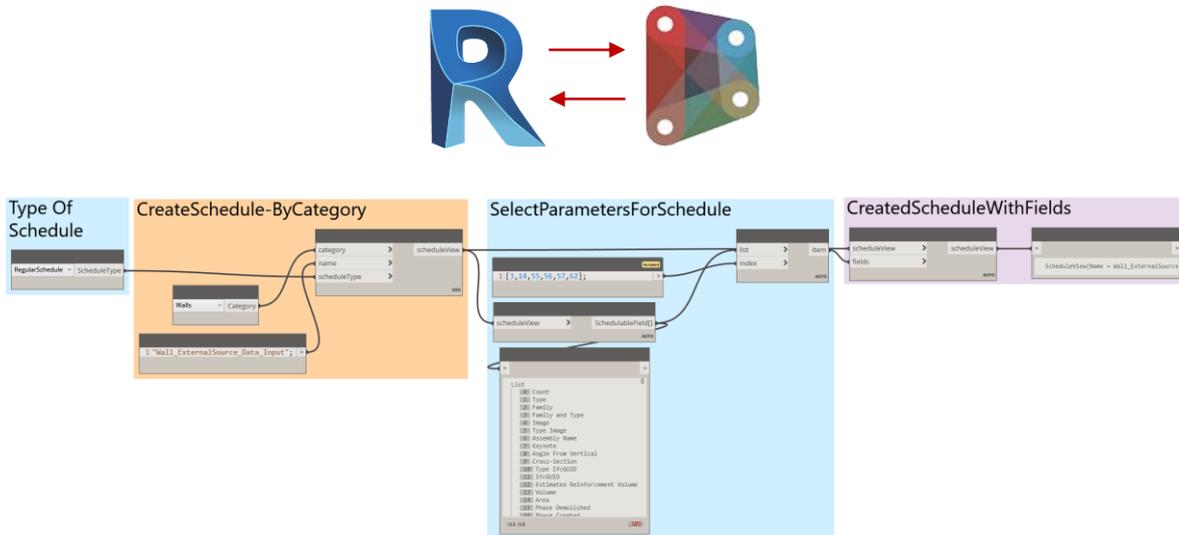


Figure 17 – Dynamo Script created to automatic generation of Schedule in Revit

BIM promotes bi-directional workflow performing updates automatically whenever the model changes, updating any technical drawing, schedules, presentation graphical information within a file, and linked ones. A proper BIM works as a data repository by adding data to geometry. The way to do it is by creating parameters that can be grouped, scheduled, exported, complemented, and imported back to fill parameters gaps. Scheduling data also is used for management goals and be used on other platforms.



The ability to retrieve data from the authoring tool and use them in management platforms saves time and avoid errors, and expand the boundaries of the communication by sharing these data, and getting updates almost instantly.

The AEC sector has shown progress on shifting the key to the digital revolution led by BIM and sequential process for running several kinds of studies including energy-related, whose results are useful to perform life cycle assessments and promote reductions on the asset’s environmental impact even after handover. The data provided by these sequential virtual calculations generates results for operational phase and decommissioning, and also for life extension.

BIM-based processes depict with transparency building’s details, generates scheduling for construction and maintenance, aids on investment calculation for improvements, payback simulation

and their use is strategic on the efforts aiming Certifications, increasing their incorporated value and improvements toward energy-saving and avoided carbon emissions throughout the life cycle of the building.

The innovation in the sector evolves constantly and creates several ways to use BIM-generated data in operational and management software. The energy consumption investigation uses BIM data imported into dedicated energy calculations software seeking complex and optimized results also used to calculate the impact on the environment.

4.3. BIM for existing buildings

Buildings have a general life span of 60 to 75 years. It changes according to countries, material quality, weather characteristics, and others. For such long-lasting assets to think about the relations between immediate use, its impact and post-use is a moral responsibility. Data harvesting and use is no longer a challenge since virtual modelling uses data from several sources, for several other uses and calculations. The current challenge is to use data in a clever and useful way.

Building Information Modelling processes data about a construction project or structure in the form of three-dimensional graphical representations of elements (e.g., doors, beams, etc.), which can be further associated with information about other characteristics of those elements. It is possible for the graphical representation of an element, taken alone, to suggest that greater accuracy or intention can be attributed to the element that is the case. (LOD Spec 2020).

Develop an existing building's BIM can be a challenging task due to the level of data needed. Built stock tends to be considered old and so without much information and data. Surveying is necessary and general knowledge about the building as well. Considering the main goal as nZEB requirements and focusing on construction materials to reach them, the level of detail needed to simulate a material behaviour includes creating or enriching an existing material library or creating its own due to existing conditions. The previously calculated thermal properties need to be included in the model.

According to (Helander and Singh, 2016) modelling for renovation with facility management goals require inventory models – as-built and existing MEP understanding the existence of elements of uncertainty.

Following Helander, the model should then be created according to the LOD Framework as LOD 300, graphically represented as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

4.4. BIM for refurbishment

According to (Sanhudo *et al.*, 2018) building for retrofitting, renovation and recovery requires data acquiring and their inclusion in the model. The methods for acquiring information of an existing buildings and the generation of a BIM can be both destructive and non-destructive. Non destructive method can be performed by laser scanning, photogrammetry and thermography, which generates data for the virtual construction of the building, and for maintenance and management purposes, such as

the actual model generation, the ability to perform analysis with acquired thermal data, and providing the export of data schemes such as Industry Foundation Class (IFC) and .gbXML.

For the research, the same model was developed in 3 different ways by evaluating the impact of high-performance materials on Roofs, External Walls and Floors as an attempt to perceive the decrease in the energy consumption value after running an energy analysis. The study case will follow one of these methods, taking into consideration the following phases after the development of the BIM model.

4.4.1. Modelling with Phases – One Model, two phases

This modelling style uses one model and a Phasing tool inherited in Revit 2021. The phased model is useful because it allows better control over the modelling, scheduling based on phases to keep track of material quantities.

Phase Existing (P.Ex.): developed to simulate the existing conditions of the building by modelling multi-layered types. The attempt includes creating new materials with close-to-real thermal and physical properties applied to them. The properties were acquired by a calculation performed in an Excel sheet following ISO 6946/2017. The final value varies by type and is grouped under the Green Building Properties area. Ideally, a complete and detailed field survey is required to build an As-Is BIM simulating the existing conditions and thermal performance of the existing.

Phase Insulation (P.In): the creation of wall, ceilings, and floor types with insulation materials chosen according to their insulating performance aiming to the increase combined resistance value. Attaching the existing types with the new ones, energy consumption values decrease. The new materials have their thermal properties edited in Revit according to thermal data provided by their EPD, but their performance data couldn't be calculated in Revit. The same process from Phase Existing applies here.

4.4.2. Split Models

This modelling strategy follows the same data acquiring process from Phase Existing but each phase is now an independent file. Types are built as multilayered objects and energy consumption, instead of decrease with the addition of layers, increased. Also the material general quantification changed after including the insulation layer.

4.4.3. Linked models

This third approach develops by disciplines, where the Architecture model hosts the Structural model as a link. Although it is a common practice in the industry for lowering file size, the carbon emission calculation tool didn't recognize the linked model and didn't include the structure in the embodied carbon results. Due to the need of calculating structure embodied carbon, this attempt wasn't pursued.

4.5. Common Data Environment

To digitalize the sector, it is necessary to connect all relative data and allow teams to communicate and develop their tasks over one single source of data and information. Common Data Environments (CDE) are secure and authorization-only cloud spaces for concentrating graphical, non-graphical, and project documentation related to a design project. A CDE can be accessed through any device with an internet connection and is hosted on servers across the globe.

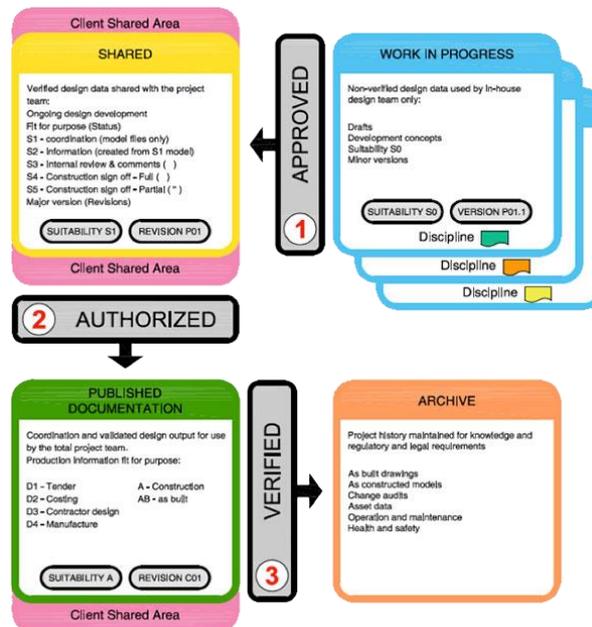


Figure 18 - Development, organization, and management of production information for the construction sector (BS 1192: 2006)

4.6. BIM and Facility Management

Building Information Modelling applied to Facility Management integrates the multiple tasks required to manage an asset by the means of data, adding the efficiency layer over the building use strategy. The use of a BIM model for operational and management allows the adoption of data to perform the needed improvements for the extension of the building's life design and construction process, for task definition, resources management and risks prevention. Also, follow the consumption of energy and water during the life cycle of the building, planning and scheduling maintenance of equipment, plan for replacements of components in a controlled and planned way. All these capabilities increase if the building operates with sensors, leveling up the standard of the data usage. This research does not include the issue of sensors but suggesting its use aims to support the qualification of the BIM for operation and maintenance as BIM Maturity Level 3. Communication between data is strategic to the O&M phase since it allows systems and performance visualization, control of building components locally or remotely due to dynamic updates in the cloud.

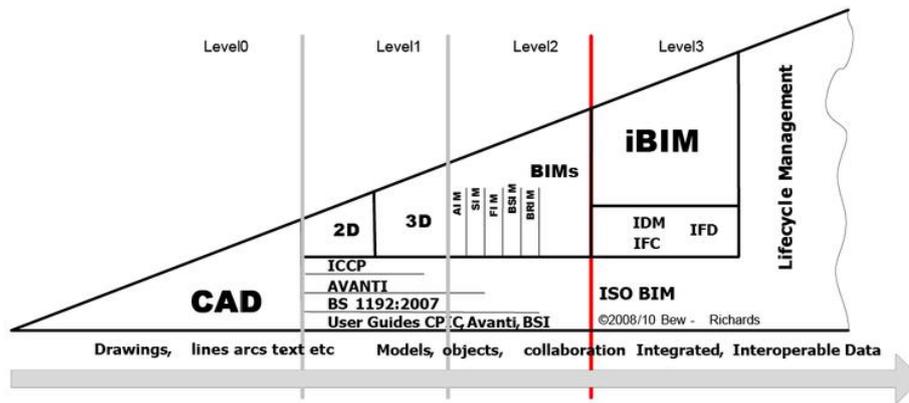


Figure 19 – The UK BIM Maturity Model (GCCG, 2011)

Energy consumption is a result of envelope’ conditions and functioning buildings systems. Materials that compose the envelope degrades with time but their use and service life can be followed and their maintenance works, easily planned. The BIM can aggregate data related to the service life of every item included in the model and used for scheduling and planning towards a stable operation.

The construction material manufacturers include the service life of their products in manuals and installation guides. This information should be included in the model, connected to the element as part of building maintenance plans. The building life cycle scheduling provides a cost-efficient way to avoid overpayments. This level of data referencing is important for energy efficiency-related issues when the performance of equipment is an essential variable for the implemented strategy aiming for a stable energy provision.

5. LCA - LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is a scientific method for evaluating the environmental impact of a product, a process, or a system based on several environmental factors at different stages of its life cycle from raw material to disposal.

A Life Cycle Assessment calculates the environmental impact by the means of indicators. The material's manufacture process release gases into the environment and their impacts are the following:

- **Global Warming Potential:** measures the increase of the concentration of greenhouse gas in the atmosphere;
- **Acidification:** measures the rate of water acidification, increasing the occurrence of “acid rain”
- **Eutrophication:** increase of plants in delicate ecosystems caused by unbalanced amount of nutrients;
- **Ozone Depletion Potential:** depletion of stratospheric ozone layer increasing sun's UV-A and UV-B radiation, impacting fauna and flora.
- **Formation of Ozone Lower Atmosphere:** impact the generation of toxic smog and causing damage to the respiratory system.

European Commission evaluates that European buildings are responsible for 40% of energy consumption and release of 36% of GHG emissions throughout building life cycle – from cradle to grave, not considered materials circularity or recycling. Each European country develops its strategies towards 2050 and is responsible for sharing its strategic plan with the EU. Due to the immense difference in resources supply and climate conditions, it is impossible to define the same rule for every country.

Most of the life cycle assessments currently performed consider sections A1 to A5, the material manufacture stage. By excluding or not defining the emissions from phases B to D in the LCA means that emissions related to operational and decommissioning stages are not considered and so, the results are miscalculated, ignoring the impact of those in the environment. The operational phase of a building has the highest energy consumption rate and as a result, a high level of carbon emissions.

5.1. Life Cycle Assessment focused on low carbon emission material's definition

The European Standard EN 15978/2011 defines the Calculation Method for the sustainability of construction works known as Life Cycle Assessment, which quantifies environmental information for buildings energy performance for either new or refurbishment projects, covering all stages of the building and is based on data obtained from Environmental Product Declarations (EPDs). To perform an LCA for an existing building based on a BIM model the designer needs to generate a model with sufficient data related to the existing, where the calculation is based on the existing material volume

which allows the correct embodied carbon calculation. According to (Genova, 2019) the needed Level of Development for LCA is a combination between Level of Geometry (LoG) and Level of Information (LoI). For the LoG, the geometry of the piece/product, needs to be enriched with its name, type, function, phase and dimensions, since. The LCA results involves both geometry for materials environmental impact calculation as the effects these materials in terms of consumption.

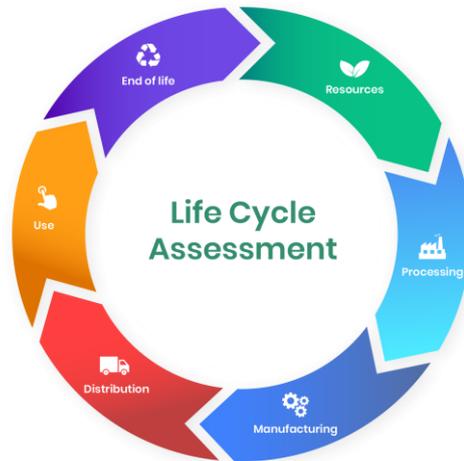


Figure 20– Life Cycle Assessment – Circularity Sequence

The European Standard, EN 14040:2006 – Environmental Management – Life cycle Assessment – Principles and Framework provides the method to perform Circularity in the AEC sector. By qualifying the existing by inventory analysis, defining goals and scopes and calculating their impact , it is possible to evaluate the potential of carbon emission reduction. The means to it includes the maintenance of products and materials in use by renovating or recovering them. Any generated waste from demolition works should be recycled, repurposed, or reused on site.

The practice of any of these solutions related to the D stage and qualifies the extension of the embodied carbon, not as Grave, but back to Cradle, reintroducing those materials into the construction value chain which is calculated as a benefit to the environment. The amount of non-generated carbon emission is included on the carbon calculation as a positive impact, located in the External Impacts section of the life cycle assessment.

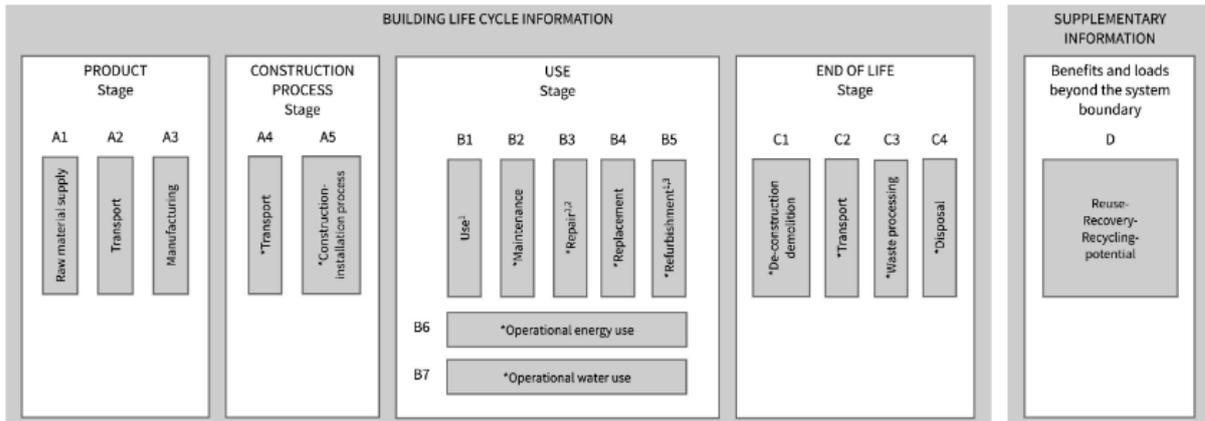
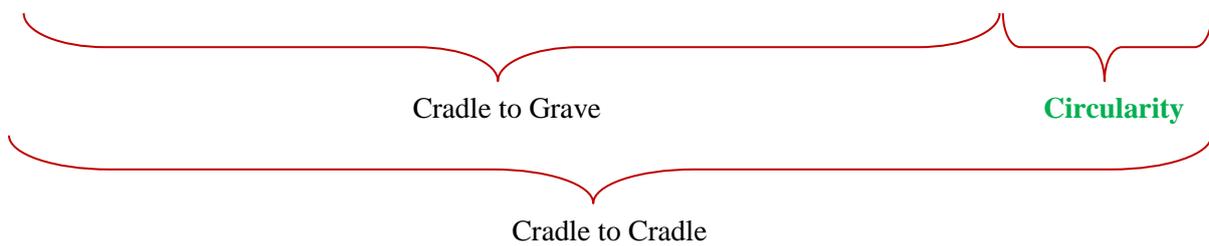


Figure 21 – Building Life Cycle – from Cradle to Cradle



Project	Concept	Design	Sourcing	Building	Operation	Renovation
Siting, knock down/refurbish	Concept design	Technical design	Procurement / specification	Construction process	Building in use	Refurbishment / rebuild options
Site choices	Conceptual	Whole building	Specification	Monitoring	In-life tracking	Renovation
Early phase LCA	Baseline LCA Transport design LCA	Structural LCA Architectural LCA Services LCA Interior design LCA Certification LCA	Choose by EPDs Responsible sourcing Material efficiency	Site carbon/LCA	Carbon tracking CSR reporting	Major renovation Interior design LCA Knock down or rebuild choices System replacement
	LCC tools				Cost tracking	LCC tools
	Risk tools				Extensions	
	Climate adaptation	Material durability			Food supply CO2	

Figure 22 – LCA and LCC for refurbishment works. Needed tasks to promote general savings based on the existing asset.

The including LCA and LCC of Operational and End of Life is crucial to achieve the EGD goals of reducing energy consumption and environmental footprint in the AEC sector. The environmental impact assessment during these phases is not well documented due to lack of practice and

misunderstanding over the advantages related to energy and financial savings potential. Although it is recognized as an urgent task to address the use of building stock, the process needs operational data from the existing building, calculates its embodied and operational carbon, its energy consumption, and annual cost. With those, it is possible to evaluate scenarios for the building renovation where energy saving and low carbon emissions are the focus of discussion. Another reason life cycle assessment for buildings is at the center of the sustainable discussion is the Certification points provided by entities to designs that prove their low carbon footprint by including LCA reports to it, also need for construction licensing approval in some countries.

5.2. Life Cycle Cost Analysis – LCCA

Life Cycle Cost Analysis (LCCA) is also a scientific financial-based method for estimating the cost of owning or running an asset. LCCA considers all the costs associated with the asset, from obtaining to disposal. The analysis becomes the ultimate tool to evaluate investment level for decision making between renovating or not. Related to nZEBs LCCA compares cost-benefit between chosen material and maintenance obligations, depicting if the goals of nZEBs can be reached or not, with most cost efficiency and lowest possible emissions. The ultimate way of displaying and connecting all data is usually with interactive diagrams.

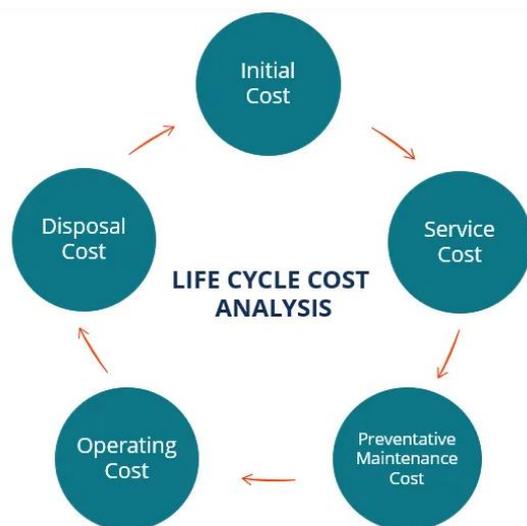


Figure 23 – LCC approach

Life Cycle Cost Analysis (LCC or LCCA) is an objective method for measuring and managing the life time costs of any project or asset. In construction, it enables design options comparability from a life time perspective to reduce overall costs.

5.3. Environment Product Declaration (EPD):

According to EPD International, the Environmental Product Declaration (EPD) is shared by manufacturers to demonstrate their commitment to measuring the environmental impact of their products transparently and includes information from phases A1 to A3, from raw material extraction until selling for installation. The EPDs information provided by manufacturers is verified by third

parties and after the EPD can be used. Even though construction materials can come from anywhere, the EPD defines the value of transportation impact according to the availability of the product in the globe. A material with a national line of production tends to show a lower ecological footprint on the transportation phase (A4) of the building life cycle assessment, the worksite is located in the same country. The EPDs are reliable sources of information and can be used for maintenance planning, modelling, communication, approvals, manual consultation, among others.

The EPDs carry, on their written document, the information about emissions released due to its production for evaluation and also properties related to thermal behaviour, and allow the user to calculate the performance inside a virtual environment for simulation. There are three ways of using the information provided by EPDs in a BIM: They are:

Using Machine Readable EPDs: a Machine Readable EPD is a document that can be processed by computers and can be used to optimize digital processes due to its structure. EPD International¹ has within its database machine-readable EPDs provided by some companies. They can be searched through databases like Environdata, EPDTurkey, Reference_data and INDATA². The results are available online as Process Data Set or downloaded as a .xml structure data file format. An XML file is a structured data format that can be imported into Excel. The imported data can be incorporated into the BIM model using Dynamo scripts for adding value to new or existing parameters.



To access a machine-readable EPD a login and password are needed. Data in EPDs have issuing day and validation day, so any data retrieved by an EPD has to be reviewed from time to time to follow to continuous LCA in case of reapplication of that specific product. As an interesting aspect of structured documents, it follows in this Research the attempt of using data from this kind of file to create types in Revit.

EPD®																	
THE INTERNATIONAL EPD SYSTEM																	
Process Data set: 12.5 mm Plasterboard Knauf A-ZERO (en) en																	
Process information																	
Modelling and validation																	
Administrative information																	
Environmental indicators																	
Indicators of life cycle																	
Indicator	Direction	Unit	Production A1-A3	Transport A4	Installation A5	Use B1	Maintenanc B2	Repair B3	Replaceme B4	Refurbishm B5	Operationa energy use B6	Operationa water use B7	De-constructio C1	Transport C2	Waste processing C3	Disposal C4	Recycling Potential D

Figure 24 – Extract of Machine Readable EPD, Environmental Indicators section

¹ <https://data.environdec.com/processList.xhtml?stock=Environdata>

² Available data stocks while the production of this paper.)

The XML importing process to Excel is shown in the image below:

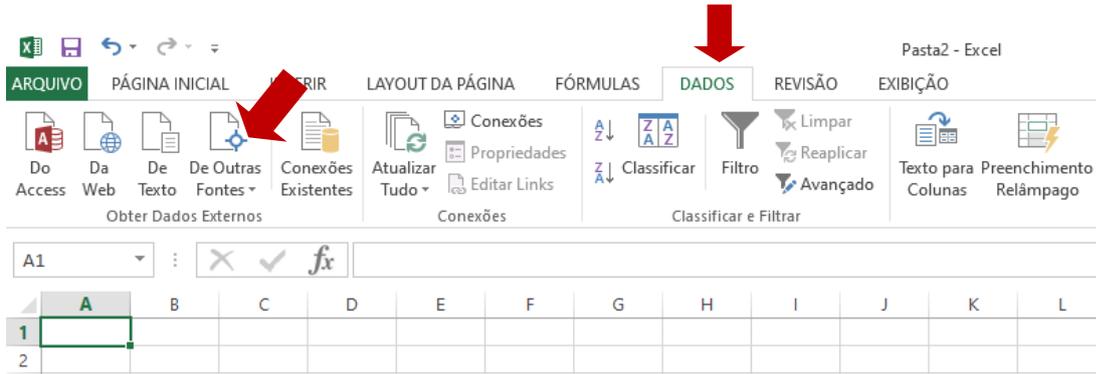


Figure 25 –Importing data from . XML file into Microsoft Excel

The XML can be opened in Excel by choosing DATA > OTHER SOURCES > IMPORT XML and will be presented like the following.

version	ns3:profile	ns5:UUID	ns1:baseName	ns2:lang1	ns5:synonyms	ns2:lang2	name	ns5:class	lev	class	type	ns1:r	ns5:r	ns5:d	ns5:u
1,1	EN_15804	daa1778e-be8f-12.5 mm Plaster	en	S-P-01937	en	The Inte Construction products	0	2	Reference	1	2020	2025	V		
1,1	EN_15804	daa1778e-be8f-12.5 mm Plaster	en	S-P-01937	en	The Inte Boards	1	2,3	Reference	1	2020	2025	V		
1,1	EN_15804														
1,1	EN_15804														
1,1	EN_15804														

Figure 26 - Locating data retrieved from EPD

This data can be added to a BIM model manually or by Dynamo script.

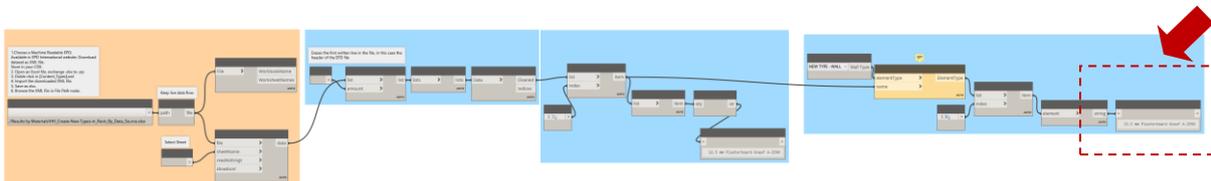


Figure 27- Dynamo script for creating a new type of wall with data from Machine Readable EPD

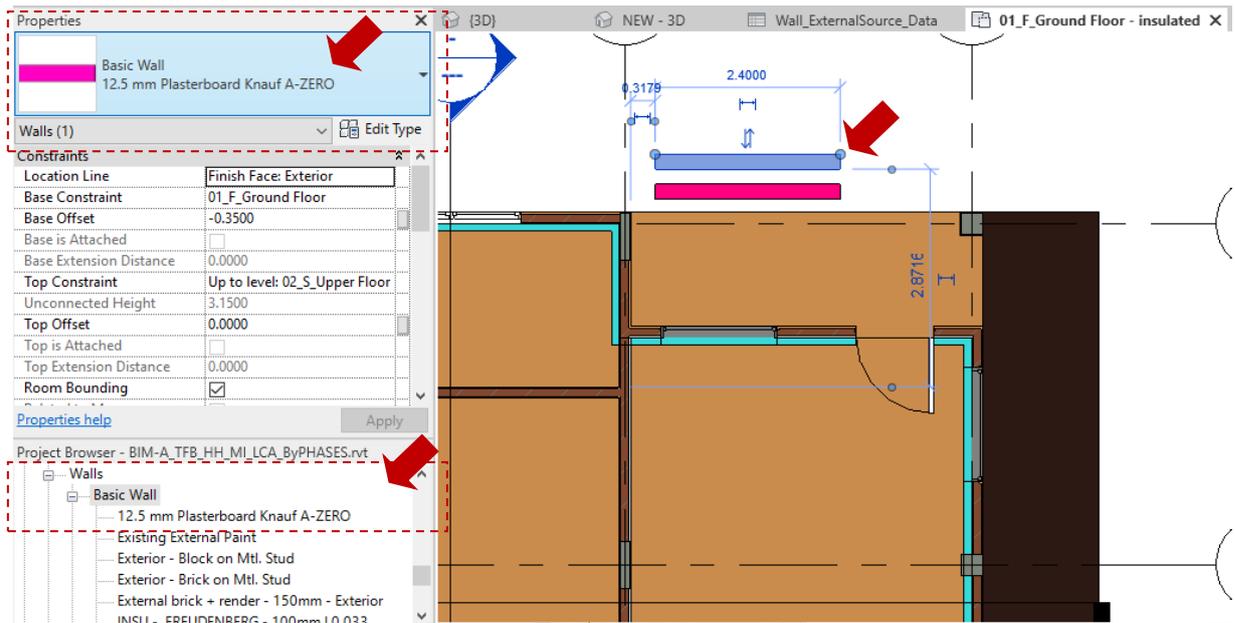


Figure 28 - The new type created with Dynamo included in Revit 2021

This example relates to an insulation product. The data provided by the EPD can be added to BIM by the means of parameters later added to management systems for reference; it contains the number of the EPD which makes it easier to search for another kind of data, to keep building documentation up to date, etc. The MREPD does not provide data about the thermal properties of the material, but it provides detailed data about the material's environmental footprint.

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6. CALCULATION VIRTUAL ENVIRONMENT - CVE

Calculation Virtual Environments (CVEs) are services in the cloud that perform complex calculations after connecting or uploading data files or data sources to it. The calculations occur in the cloud due to the high quantities of variables and the large range of results it retrieves. These services generate files also used for interoperability goals, to bring back newly created data to BIM complementary databases. Most cloud services allow the data to be updated, as long as they are not deleted completely.

Calculation virtual environments are used for several goals, the ones included in this research are:

- Calculating thermal properties for building envelope components;
- Calculating the energy consumption of the existing building; calculated again, after insulation layer inclusion.
- Calculation of the existing environmental footprint of the existing building; calculated again, after including insulation materials. Energy consumption values are included here.

6.1. Calculating thermal conditions of the existing building

A comparison between the thermal transmission of walls provided by Revit and an Excel-based calculation with equations were performed to understand the difference between the two and how it interferes with the final results of energy consumption results.

6.1.1. Manual with equations

The task to identify the thermal properties of a material is not easy and involves a lot of calculations and variables that are the field of knowledge of mechanical engineering. The authoring tool used to develop this research has thermal properties section for each material used in the model, but the results are not reliable, so another calculation method was applied. The method is manual and calculations are done in an Excel file. The values of the material's **thermal conductivity, resistance, and heat coefficient** are available in the manufacture's datasheets, Standards, and literature.

6.1.2. Results provided by Revit

Even by changing the thermal properties of material's, thermal conductivity, and heat coefficient the results provided by Revit are not reliable, but Value for Thermal Resistance was similar in some cases. Revit's values are located in Analytical Properties on the Family Type chart while those from Excel calculation were included in the model by filling created Project Parameters by Type under Green Building Properties.

The add-in from DiRoots ParaManager is used to a fast look, export, and import back data into the model placed on the proper parameters created for the project.

<input checked="" type="checkbox"/>	GBS_Heat Transmittance (U) (W/m ² K)	Project Parameter	Common	Number	Green Building Properties	Instance
<input checked="" type="checkbox"/>	GBS_Thermal Conductivity L (W/mK)	Project Parameter	Common	Number	Green Building Properties	Instance
<input checked="" type="checkbox"/>	GBS_Thermal Resistance (R) (m ² K/W)	Project Parameter	Common	Number	Green Building Properties	Instance

Figure 29 – Created Parameters visualization using DiRootsParaManager

6.1.3. Insulation companies calculators

U-value calculation tools are generally provided by insulation companies with the inclusion of an insulation material resulting in the Heat Transfer Coefficient (U-Value) of the component after the inclusion of the insulation layer. When the composition of the component is unknown, the result is not reliable. This kind of calculator is useful for defining the appropriate insulation when the rest of the component is still under definition or if the layers are known well enough to map correctly according to the options provided by the tool. When available, the calculator provides a BIM family with the final found U-Value. The attempt of using this calculator for his research didn't get any BIM family.

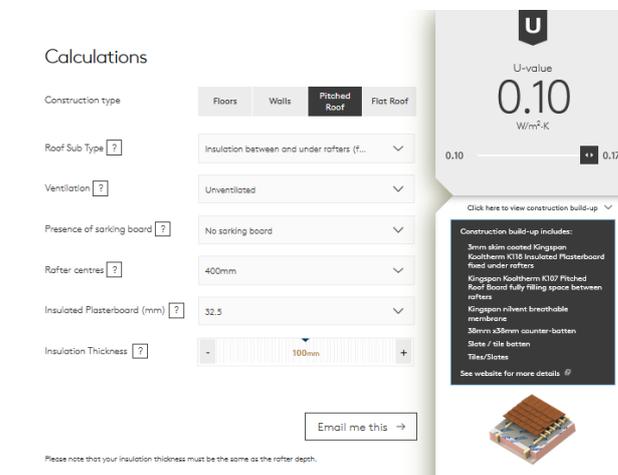


Figure 30– U-Value simulation result (Kingspan, 2021)

6.2. Building Energy Modelling – Autodesk Revit 2021, Insight, Green Building Studio

Building Energy Modelling (BEM) is the energy analytical model generated after a BIM authoring file. During the conceptual and pre-design phase BEMs can be generated with masses, enriched objects with analytical predefined building properties, or both combined. According to (Magrini *et al.*, 2020) building position and orientation helps on sun incidence controlling in both opaque and transparent surfaces, building thermal mass is responsible to control heat gain and loss when in extreme conditions, thermal regulation provides internal comfort and solar shading protects from overheating in summer. Those solutions can be implemented in refurbishment works.

For existing buildings, some variables are not changeable and need to be included like **Site/Building Location and Project Orientation**. Providing a site/building location allows the tool to consider the building's closest weather station and provides reliable temperature and air humidity variation data for heating and cooling demand simulation.

An existing building BIM is a repository of acquired data used for several calculations. Information about materials in an existing building is precious information to understand the extent of refurbishment work needed since the existing layer can be useful or not, according to its conditions. **Material's physical and thermal data** applied to objects allows the generation of a simulated energy model. Materials are used for the **Envelope definition**: Building envelope is the most important group of items needed to perform energy analysis. The envelope is responsible for providing or avoiding heat transfer through the building and avoid thermal losses to the outside.

And also defining **Rooms and Spaces**: The energy analysis process uses Spaces volume for evaluation. The correct data referred to rooms can be used to define spaces. Rooms can be exported as spaces that have analytical parameters needed for energy analysis. Spaces analytical parameters are primarily standardized according to building definition stats. They can also be individually specified according to their need and particularities. This existing performance evaluation depicts optimization strategies, which can be seen in Autodesk Insight.

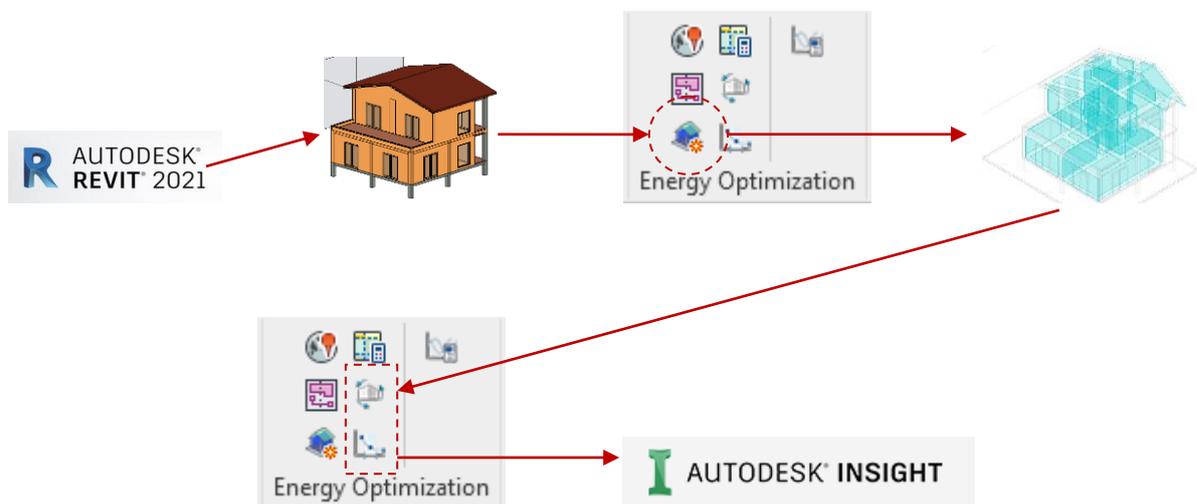


Figure 31– Sequence for Energy Performance modelling, analysis, and Cloud base evaluation

Autodesk Insight as an energy analysis tool for refurbishment

Autodesk Insight is a tool for energy analysis. It generates options for improvement and demonstrates it by energy intensity use (EIU) value and cost/m²/year (in Euro). It can be useful for refurbishment goals since it proposes optimization scenarios showing a range of graphics for better energy performance.

The tool complies with US standard ASHRAE 90.1-2019 that provides requirements for the energy-efficient design of most buildings. It offers, in detail, the minimum energy-efficient requirements for the design and construction of new buildings but also new portions of buildings and new systems and equipment in existing buildings. The use of this service for refurbishment is the showcase of modifications it can go through to decrease the EIU and the cost of annual consumption.

Each graphic provides a design strategy aiming at better performance and energy savings. The more horizontal options are the lower savings it represents. The calculation tool demonstrates which and

how (According to ASHRAE) is the most appropriate solution aiming highest impact on energy savings.

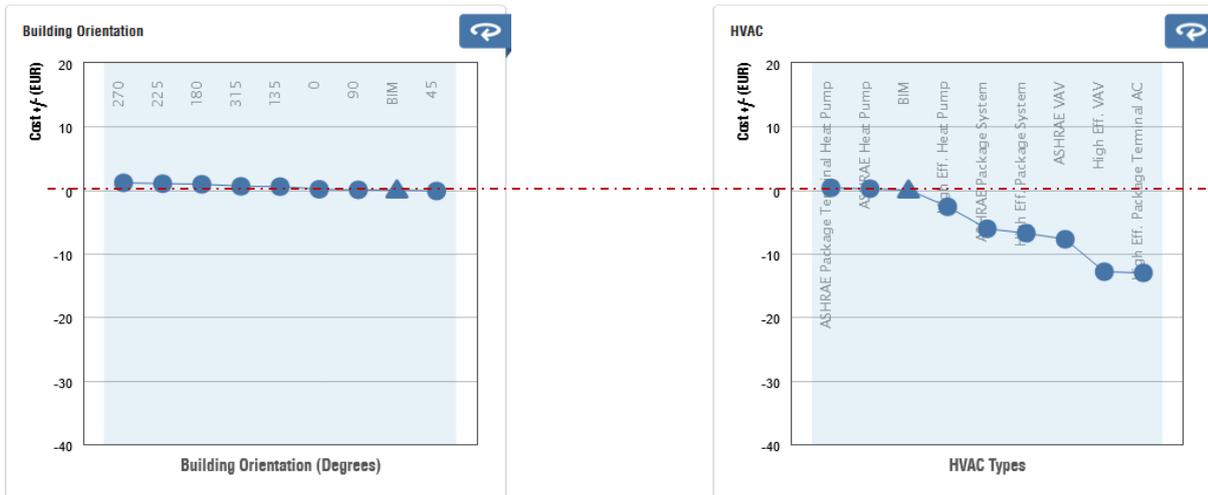


Figure 32 – The visual results provided by a virtual calculation environment demonstrating the most impactful change for a building with a balanced orientation.

Autodesk Green Building Studio (GBS) as an energy consumption and cost simulation tool

Green Building Studio provides an integrated method for evaluating the energy cost of Autodesk Insights options, allowing creating scenarios according to generated data.

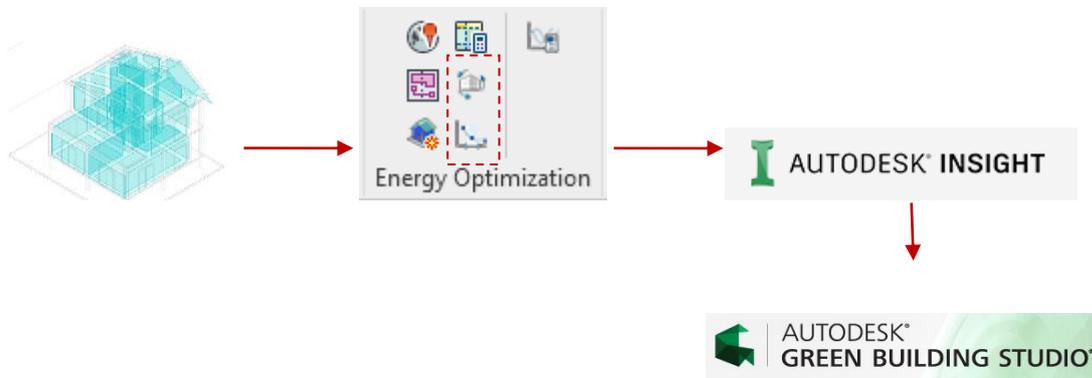


Figure 33– Sequence for Energy, water and cost calculation

The tool uses the DOE-2 engine to predict energy use and cost for buildings, annually and during the whole life cycle. The service keeps the data saved in the Cloud and it is possible to evaluate and export them for comparison and uploading on other services, for other goals, such as carbon emission quantification by inputting energy-related data.

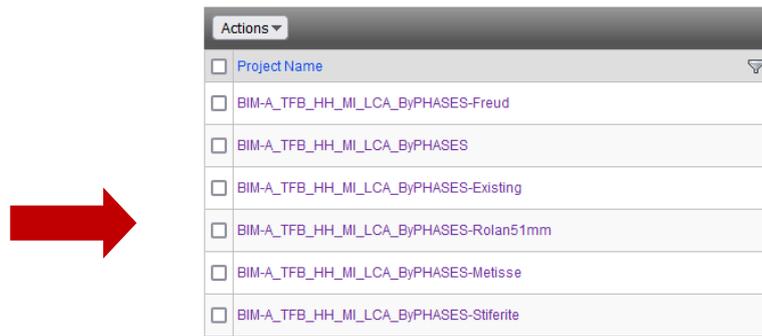


Figure 34 – Energy consumption and cost simulation run for Existing conditions phase

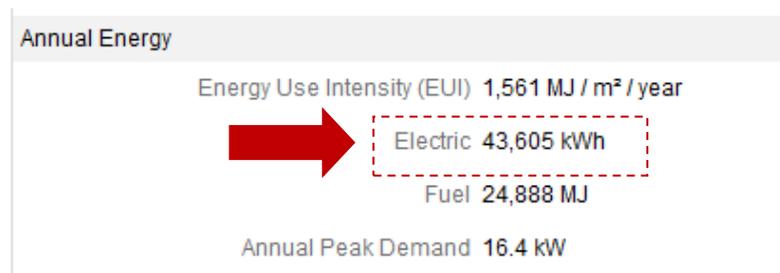


Figure 35– Annual Energy consumption for existing conditions calculated in GBS

The data is exported into file types such as:

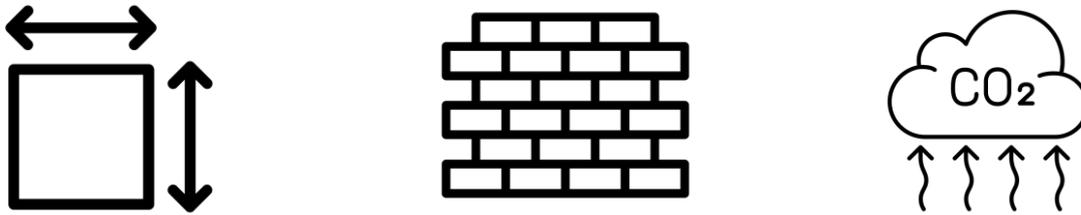
- Excel .CSV files
- Green Building Studio .gbXML files

6.3. One Click LCA for Life Cycle Assessment

One Click LCA is a cloud-based Software as a Service (SaaS) designed for carbon emission calculation. A Software as a Service (SaaS) allows a user to rent/buy/enrol in a service that provides remote digital and high processing capability, hosting results in the web to be consulted and shared easily. BIM increased general file sizes in a way that regular computers and domestic boards cannot perform well, leaving servers and cloud-based services to the calculation effort. Cloud calculation retrieves results based on inputs from multiple data sources. One Click LCA calculates the environmental footprint of construction materials, exclusively, and does that supported by several databases of materials environmental footprint reports provided by manufacturers, called Environmental Product Declaration (EPD).

Choosing an optimal material can be a strategy and a burden. The goal is to ensure that the building will be low on carbon emissions. Construction materials are currently responsible for a big slice of CO₂ emissions, over 11% of GWP. So it becomes obvious that evaluating the material's CO₂ emission rate represents an attempt on decreasing GWP emissions. Since refurbishment can generate a huge amount of waste and emissions derived from that, the challenge is to choose a high-performance material with the lowest emission rate possible. The access to the tool is by subscription to a License with a level of access to results, according to the goal of the assessment. The service provides data and

quantification of carbon emissions by selecting a material accompanied by their EPD where the manufacturer informs the life cycle assessment of 1sqm of their product.



EPDs gives data over 1m² * total area of material = calculated embodied carbon

The quality of information varies by product and validity of the document inside the database which means it needs to be constantly checked for its validity.

The total amount of carbon emissions is calculated through the whole buildings life cycle and considers carbon emissions from:

- construction material quantification input (BIM connected by add-in)
- annual energy consumption (calculated by GBS);
- water consumption (calculated by GBS);
- constructions site operations (provided by documentation related to the building, if any)
- building area (retrieved by the Authoring tool, such as Revit);
- calculation period (in years).

The more data included, the more reliable the calculation will be.

The advantage of using BIM software for carbon calculation lies in the easy retrieval of a bill of quantities and, whenever changed, it's easy to recalculate. In addition, the BIM model aggregates data within it by the use of parameters connecting documentation from local or cloud sources and avoiding time-wasting related to research. It is understood that bi-directional interoperability should allow the connections between the assigned material to the BIM object, but it could not be done until now.

The use of the software in existing buildings is a tricky task due to the sustainable characteristic of the majority of the database. To simulate it, mapping the Revit materials should be either the most basic as possible found on One Click LCA databases or materials with similar performance. This process allows a simulation of the carbon footprint baseline as starting point to the evaluation of its final footprint, with higher performance material in mind.

There are three ways of uploading data into One Click LCA. They are:

6.3.1. Add-in for Revit

After downloading and installing the appropriate add-in to the authoring tool’s version, log in to the correlated account establishing a connection between the BIM and the calculation cloud service.

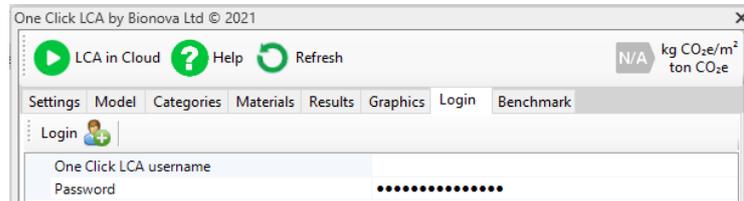


Figure 36 - Connection between Revit BIM and One Click LCA

The data contained within the BIM is extracted and displayed in the dedicated window. The add-in recognizes the categories within the model, showing all, no matter the Phase. It is possible to exclude categories from the uploading to the cloud in case it doesn’t make sense for the calculation. The cloud base service data update and data addition, seeking a complete evaluation of the desired materials. By unchecking “Included” prevents their uploading to the cloud.

Category	Included	Unit	Split objects to materials	Count
> Ceilings	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	7
> Doors	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	13
> Structural Framing	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	17

Figure 37 - Identified Model Categories visualization

The Phase selection allows filtering materials according to the Model phase selection.

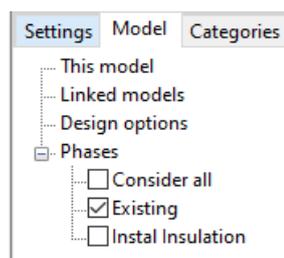


Figure 38 - Phase definition for filter materials in One Click LCA

Family	Type	Structural mat...	Material	Count	Unit	Map
Category : Ceilings - 1 Items						
Category : Doors - 3 Items						

Figure 39 – Materials identification divided by Categories

On the Materials Tab, the showcase of materials follows the check phase option. The mapped materials are not kept in the add-in tool inside Revit 2021. Once the materials are assigned to Revit’s ones they can be uploaded to the Cloud. Materials are searchable with the aid of filters. The calculation performed in One Click LCA retrieves:

- With materials mapping, building area, and calculation period: **Embodied carbon**
- With Energy, water, site operations: **Operational Carbon**, being energy mandatory.

There are many advantages of mapping materials inside Revit, such as the possibility to isolate the objects to map correctly. In case changes are made in the model during the material mapping process, refreshing the materials list will update according to the last model changes; instance parameters can be created in Revit and uploaded to cloud; and they are included in exported schedules further ahead. Type parameters cannot be sent to the cloud.

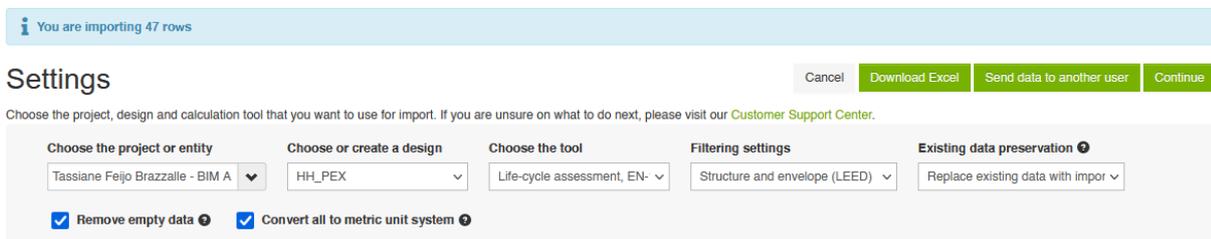


Figure 40– One Click LCA import window in the Cloud

Once uploaded, the cloud service organizes the materials placement, their quantities, and add automatically information from their mapped EPDs to fill transportation and service life, locate in the Building Material’s tab. The other tabs are enriched with data acquired from the previous calculation tools according to the sequence below which are added according to Table 1



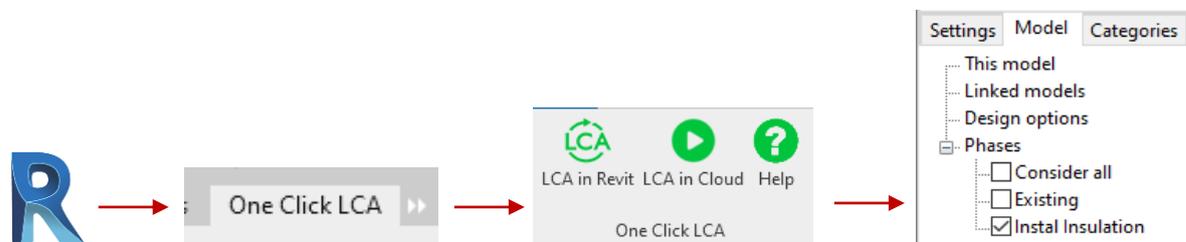
Figure 41 – One Click LCA tabs for data input, and data sources

Table 1– Data input by Software in One Click LCA / Input Model and results

Software / Documents	Data	Input mode	Destination One Click LCA	Result
Revit (By Phase)	Material quantities (m ² ,m ³ ,pieces)	Add-in to the cloud	Building Materials	Correct input, following mapping and classification system
Green Building Studio (By Run)	Annual Electricity Energy	Manual	Energy Consumption	Correct, updated manually
Green Building Studio (By Run)	Annual water use (Annual, L/year)	Manual	Water Consumption Annual	Correct, updated manually
Non calculated	Construction Site Operations	Manual	Construction Site Operations	No input
Revit	Gross Building area plan (121m ²)	Manual	Building Area	Correct, updated manually
Expected life of the building	Number (60y)	manual	Calculation Period	Correct, updated manually

The correct placement of data generates the environmental impact of the building, demonstrated in several ways based on Standard EN 15978. Changing values on tabs updates the results.

The procedure for refurbishment follows the same steps. Compare multiple materials and their calculations provides evaluating the material choices made during the refurbishment design phase and deciding which is the most appropriate way to go.

**Figure 42 – Sequence to assign LCA's database materials to Phase Insulation**

The materials are the same as the previous phase, and the new materials need to be mapped according to the desired EPD.

Since the refurbishment efforts and the NZEB goals aim to prevent C1-C4, decrease B1-B7 and emit the lowest as possible with new materials A1, a way to simulate the maintenance of embodied carbon is by checking the existing materials as Reused Material. As a consequence their A1-A3 CO₂ emissions instantly reduce. It is also needed to define their transportation value to zero, A4 is reduced.

Resource	Quantity	CO ₂ e	Comment	Transport, kilometers	Transport, leg 2, kilometers	Service life	Reused material
Brick wall from small compressed or ?	17.66 m3	0.3t - 0.1%	Basic Wall	0 Trailer combination, 40	0 Not defined	As building	<input checked="" type="checkbox"/>
Rock wool insulation, unfaced, L ? Q	8.46 m3	0.11t - ~0%	Basic Wall	60 Trailer combination, 40	0 Not defined	As building	<input type="checkbox"/>
Brick wall from small compressed or ?	5.73 m3	96kg - ~0%	Basic Wall	0 Trailer combination, 40	0 Not defined	As building	<input checked="" type="checkbox"/>
Mineral rendering and plastering mo ?	4.13 m3	17kg - ~0%	Basic Wall	0 Trailer combination, 40	0 Not defined	As building	<input checked="" type="checkbox"/>
Mineral rendering and plastering mo ?	3.93 m3	17kg - ~0%	Basic Wall	0 Trailer combination, 40	0 Not defined	As building	<input checked="" type="checkbox"/>
Mineral rendering and plastering mo ?	2.61 m3	11kg - ~0%	Basic Wall	0 Trailer combination, 40	0 Not defined	As building	<input checked="" type="checkbox"/>
Mineral rendering and plastering mo ?	0.087 m3	0.37kg - ~0%	Basic Wall	0 Trailer combination, 40	0 Not defined	As building	<input checked="" type="checkbox"/>

Figure 43 – Update to existing materials considered as reused

The reason for maintaining existing materials, instead of not considering them at all, is that Maintenance and Replacement related carbon emissions will be considered during the extension of the building’s life.

The material quantities vary according to the implemented solution and the intensity of the refurbishment level. Manually imputed data allows full control of values and is easily updated and added if needed. The assessment results exposes all design options graphically and can be downloaded as Excel spreadsheets.

6.3.2. Import Excel Sheets with Bill of Quantities

The bill of quantities follows a One Click LCA template that fills the gaps inside the cloud service if correctly addressed in an excel sheet. The upload of a bill of quantities is an advantage when the LCA is not based on a BIM model. It relies on CLASS and IFCMaterial mapping. This attempt was not pursued during this research.

6.3.3. Import gbXML file

The carbon emission calculation tool One Click LCA can also use the data stored from building performance simulation structured in .gbXML files, which are exported from both Revit 2021 as from Green Building Studio. The attempts for this section development followed the processes:

- Revit 2021 > export as gbXML for both **Phase Existing** and **Phase Insulation (Stiferite, L=0,022)**;
- Revit 2021 > energy model > GBS > export as gbXML for both **Phase Existing** and **Phase Insulation (Stiferite, L=0,022)**;

Four attempts were conducted and the results follow according to the table below.

Table 2 – Automatic Data inclusion into One Click LCA using .gbXML files

gbXML exported from:	% of identified material	Energy Consumption	Water Consumption	Building Area input	Calculation Period	insulation type
Revit (Existing model)	82,1%	Not included	Not included	120, 24m ²	Manually	None included
Revit (Insulated model - L=0,022)	79,38%	Not included	Not included	110,78m ²	Manually	No
GBS (Existing)	82,06%	Not included	Not included	116,48m ²	Manually	None included
GBS (Insulated - L=0,022)	79,38	Not included	Not included	107,58m ²	Manually	No

The attempts retrieved inconsistent data like materials not identified correctly according to the created model; the built area imported relates to internal use area, which is not the one requested by One Click LCA for the calculations even though the model has an area plan calculated as Gross Building; and no data was automatically included in the data tabs. To understand the imported data from GBS to One Click LCA the hardcode file was consulted to evaluate the identification of materials and built area value given by the file.

Attempt 01: Revit 2021 > export as .gbXML - Phase Existing | Energy Analysis Settings

```

12 </Location>
13 <Building buildingType="SingleFamily" id="aim0013">
14 <StreetAddress>Via San Dionigi, 20139 Milão</StreetAddress>
15 <Area>120.2424692</Area>

```

Attempt 02: Revit 2021 > export as .gbXML - Phase Insulation L=0,022 | Energy Analysis Settings

```

12 </Location>
13 <Building buildingType="SingleFamily" id="aim0013">
14 <StreetAddress>Via San Dionigi, 20139 Milão</StreetAddress>
15 <Area>110.7801459</Area>

```

Attempt 03: Revit 2021 > energy model > GBS > export as gbXML > Phase Existing | Energy Analysis Settings

```

12 </Location>
13 <Building buildingType="SingleFamily" id="aim0013">
14   <StreetAddress>Via San Dionigi, 20139 Mil?o</StreetAddress>
15   <Area>116.47797</Area>

```

Attempt 04: Revit 2021 > energy model > GBS > export as gbXML > Phase Insulation L=0,022 | Energy Analysis Settings

```

12 </Location>
13 <Building buildingType="SingleFamily" id="aim0013">
14   <StreetAddress>Via San Dionigi, 20139 Mil?o</StreetAddress>
15   <Area>107.58465</Area>

```

```

21336 <Material id="aim0175">
21337   <Name>HH_STIFERITE PUR+EPS L=0,022: 0.06 [m]</Name>
21338   <R-value unit="SquareMeterKPerW">2.8409091</R-value>
21339   <Thickness unit="Meters">0.0625</Thickness>
21340   <Conductivity unit="WPerMeterK">0.022</Conductivity>
21341   <Density unit="KgPerCubicM">185</Density>
21342   <SpecificHeat unit="JPerKgK">1470</SpecificHeat>
21343 </Material>

```

Figure 44 – Consulting file hardcoded to identify the insulation material– GBS –L=0,0222

By importing the .gbXML file exported from Revit it does carry the insulation material name, but the automated process of mapping into the LCA platform doesn’t happen properly.

6.4. Photovoltaic Geographical Information System – European Union

The Photovoltaic Geographical Information System (PVGIS) provided by European Commission calculates the potential of photovoltaic panel’s energy generation using Geographical Information System (GIS), connecting panel data provided by manufacturers to the geographic coordinates of the project. It retrieves detailed values about PV generation and exports data files such as .csv and .json files.

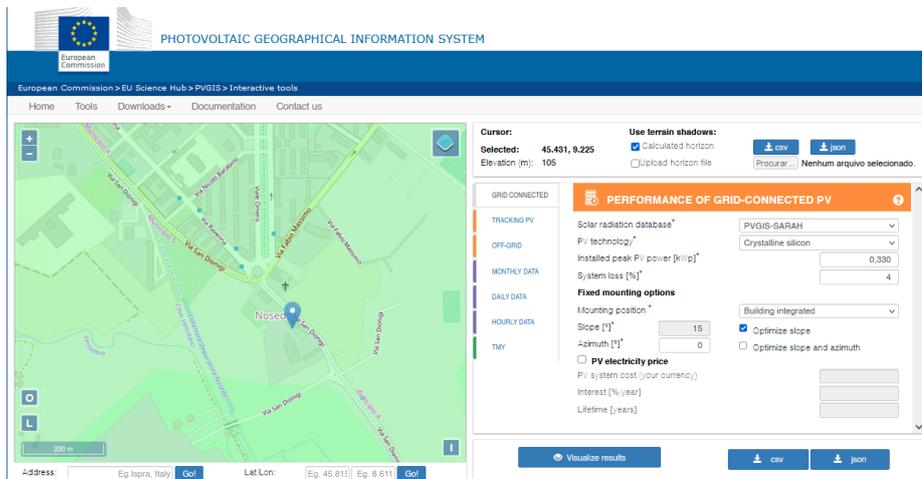
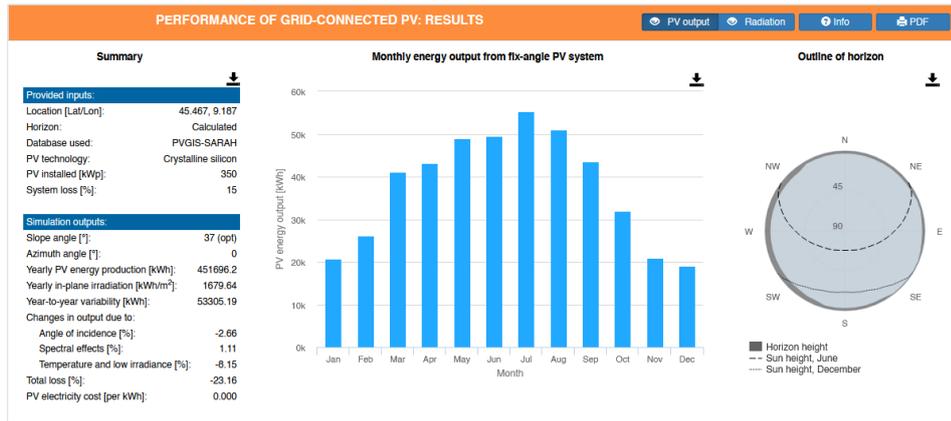


Figure 45 – PV virtual calculator (PVGIS, 2021)



Last update: 15/10/2019 Top

Figure 46 – PV generation simulation result (PVGIS, 2021)

The calculated value can be manually included in the section **Energy Consumption Annual** in One Click LCA, following the equation:

$$\text{Energy Supply} - \text{Energy Demand} = \text{Exported Energy}$$

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7. CASE STUDY: HOUSE HILL - MILAN

The study case is the opportunity to test the developed research based on simulation. Dealing with existing buildings allows understanding the environmental impact of keeping them standing. This research is done under the assumption that is environmentally responsible to deal with a built asset seeking to comply with nZEB goals.

The case study aims to connect the modelling process, data acquisition, processing, and visualization of an existing house towards NZEB, lowering its consumption by replacing and adding materials followed by the inclusion of a static amount of generated renewable energy. In the topic of carbon emissions, an existing building still emits carbon when we understand that operating something emits, decommissioning something emits, deconstructing, and reconstructing emits.

The process is structured in a way that every used software generates data to add on the final service in the cloud for Life Cycle Assessment.

7.1. BIM adopted strategy

The Study Case model is a single-family house, with residential use, hypothetically located in southwest Milan. The building is composed of two stories and has a gross built area of 120m² and a gross floor area of 80m².

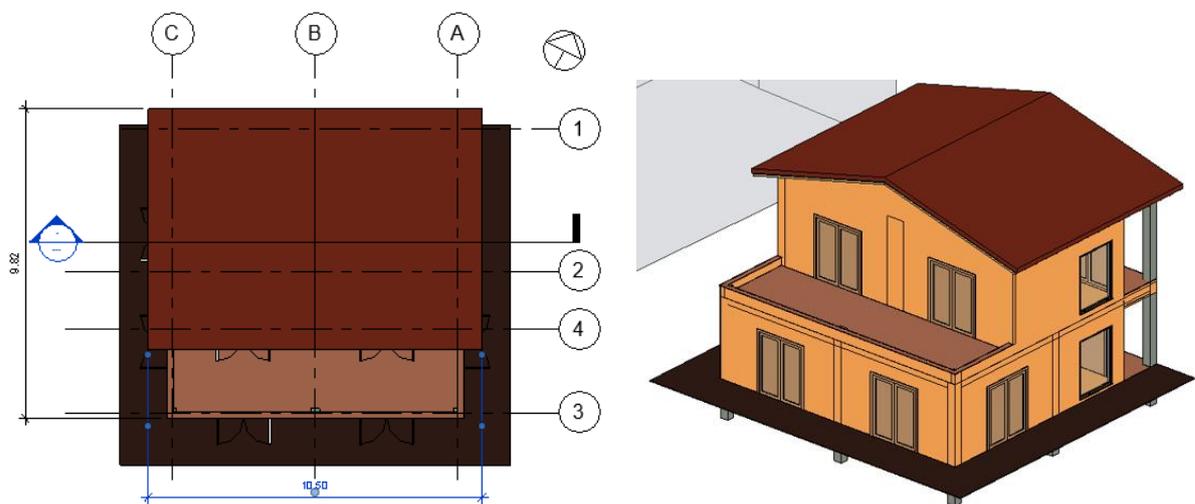


Figure 47 – The study case house plan view and perspective

The authoring tool is Autodesk Revit 2021 and the development of the BIM has two phases:

- Phase Existing (P.Ex.): also known as As-Is Model and Baseline.
- Phase Insulation (P.In): also known as Insulated Model

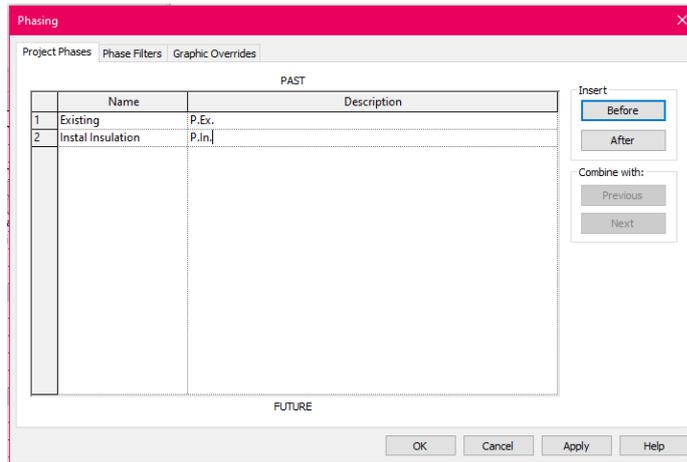


Figure 48 – Definition of Phases in Revit 2021

7.2. Creating the As-Is Model:

The model is developed using system family types for walls, roofs, floors, windows, and doors.

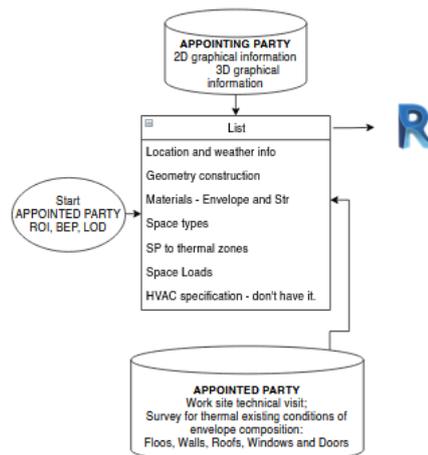


Figure 49– List of information needed to populate BIM As-Is

The image shows two parts. On the left is the 'Project Information' dialog box. It has fields for 'Family' (System Family: Project Information) and 'Type'. Below is a table for 'Instance Parameters - Control selected or to-be-created instance' with columns for 'Parameter' and 'Value'. The 'Other' category is expanded, showing parameters like 'Project Issue Date' (14/06/2021), 'Project Status' (Detailed materials), 'Client Name' (Tassiane Feijo Brazzalle), 'Project Address' (Via S. Dionigi, Nosedo, Milano), 'Project Name' (HouseHill), and 'Project Number' (0002). On the right is a table titled '<Multi-Category Material Takeoff-Existing materials>'. It has three columns: 'Material: Name', 'Material: Area', and 'Material: Volume'. The table lists various materials and their corresponding area and volume values.

Material: Name	Material: Area	Material: Volume
Birch	138.59 m²	1.40 m³
Concrete, Plywood formwork	355.87 m²	25.51 m³
Glass	30.86 m²	0.17 m³
HH_Brick Common, Brown	242.65 m²	23.37 m³
HH_Clay Roof Tiles	83.16 m²	1.25 m³
HH_Concrete, Sand/Cement Screed	155.77 m²	12.77 m³
HH_Gypsum Plaster Board	13.45 m²	0.17 m³
HH_Oak Flooring, Espresso	46.35 m²	0.93 m³
HH_Plywood, Sheathing	83.16 m²	1.25 m³
HH_Render, Tan, Textured Orange	194.56 m²	4.22 m³
HH_Render, Tan, Textured White	293.62 m²	6.54 m³
HH_Wood Floor Teak	133.32 m²	2.40 m³
Terrazzo	25.22 m²	0.45 m³
Grand total	1796.57 m²	80.42 m³

Figure 48 - Study Case Project Information and Material Takeoff

Calculating Thermal Properties with Excel

The values of the material’s **thermal conductivity, resistance, and heat coefficient** were acquired from traditional construction materials from UK Design Building tables. They were used to calculate the Wall’s **thermal conductivity, exterior and interior surface’s to simulate the multilayered wall’s heat coefficient and resistance**, according to each material layer composition.



Equations	Material Values and calculations					Single Wall Calculation				
	Thickness (m)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Heat Transfer Coefficient [W/(m²K)]	Area (m²)	Wall's Thermal Resistance (m²K/W)	Wall's Thermal Conductivity (W/mK)	Exterior Surface Thermal Resistance (m²K/W)	Interior Surface Thermal Resistance (m²K/W)	Wall's Heat Transfer Coefficient [W/(m²K)]
	D (m)	$\lambda = D/R$	$R = D/\lambda$	$U = \lambda/D$	A	$R_{tot} = R_1 + R_2 + R_{se}$	$\lambda_w = D/R$	$R_{se} = D_e/\lambda_e * A_e$	$R_{si} = D_i/\lambda_i * A_i$	$U = 1/(1/R_{se} + R_{tot} + 1/R_{si})$
Materials										
Exterior Wall										
Plaster Orange	0,024	0,500	0,047	21,277	16,040	0,260	0,577	0,754	xxx	0,342
Brick	0,103	0,620	0,166	6,019	xx	xx	xx	xxx	xxx	
Plaster White	0,024	0,500	0,047	21,277	15,900	xx	xx	xxx	0,747	



Figure 50 – Thermal properties calculation in Excel

Creating, managing and enriching Parameters

Type parameters were created to enrich the model with acquired data along with the model’s development. The parameters are filled with data and information, some of them used for comparison purposes and model enrichment following the need, others to improve the documentation research capabilities provided by BIM. Using BIM as a repository allows time-saving by accessing different places – local files, server files, URLs, third party documentation inside the model and connected to the respective geometry.

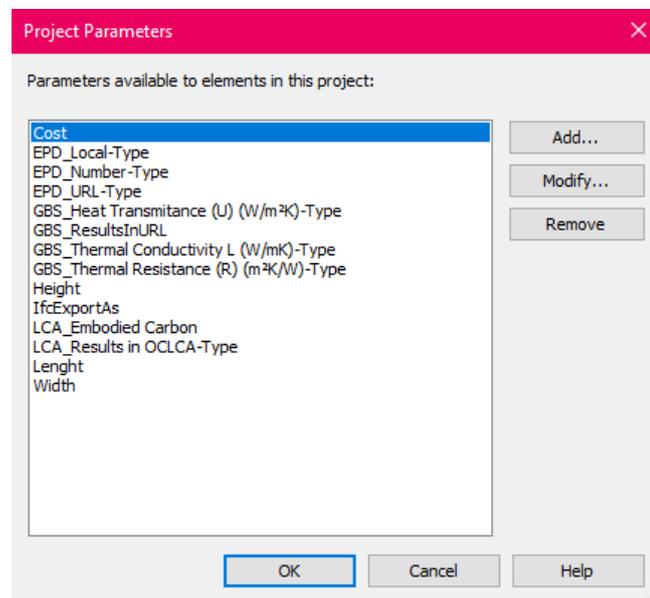


Figure 51 – Created Parameters to include data within the model

Parameters are created whenever there’s a need for data extraction power and they are managed with third-party DiRoots ParaManager.

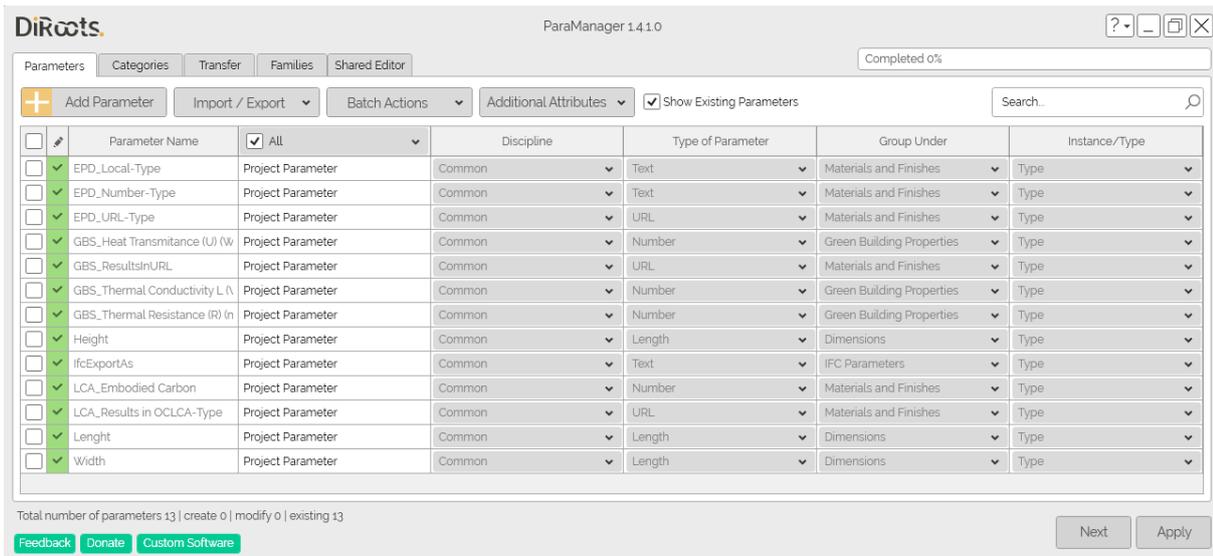


Figure 52 – DiRoots ParaManager screen for Parameters management

The previously calculated results are added to the model under Green Building Properties using a second add-in from DiRoots, SheetLink. The add-in export spreadsheets with the selected parameter which are filled in and transferred back into the model.

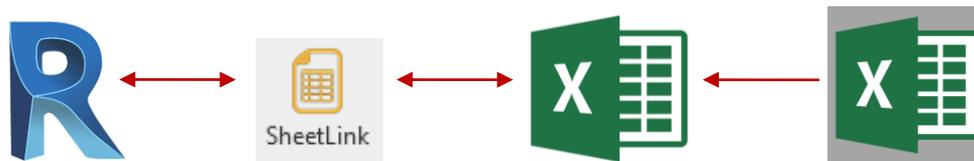


Figure 53– Interoperability between Revit’s data and Excel Spreadsheets using DiRoots SheetLink export and import power (Bi-Directional).

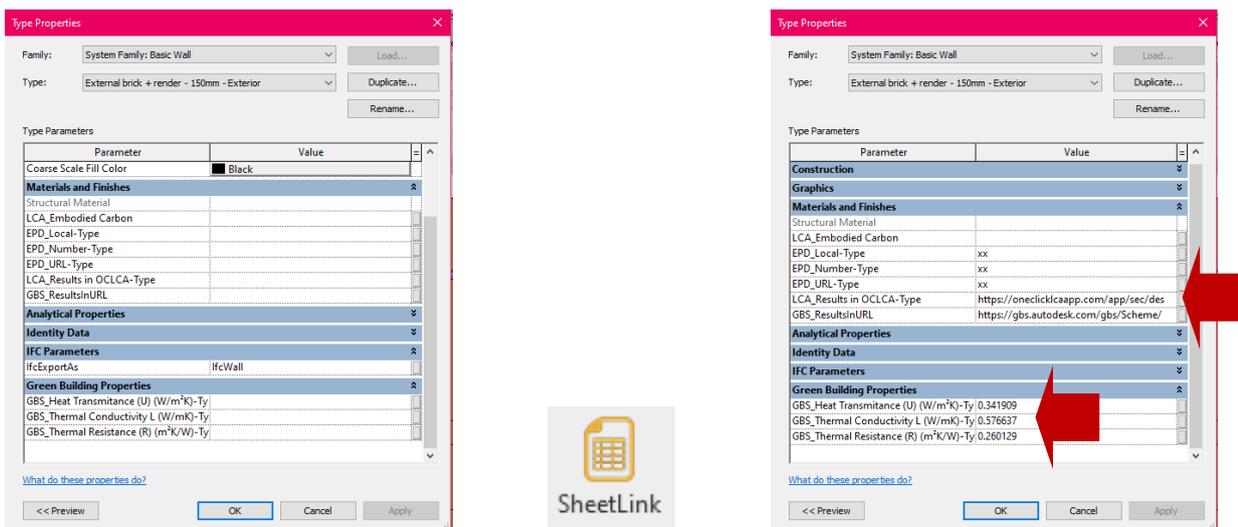


Figure 54 – All external walls with values from Excel placed in Type parameters

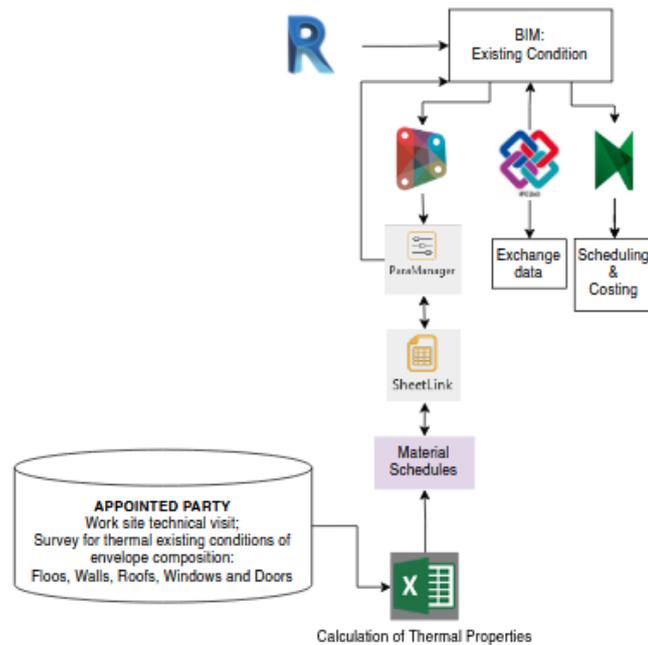


Figure 55 – Data filling process between BIM and Excel spreadsheets and file export options for managing purposes and model data exchange

From BIM to BEM – Phase Existing Baseline aiming improvements

To improve energy consumption rates and evaluate energy conservation strategies for an existing building it is essential to understand how the existing one behaves. The energy model is generated in Revit by the built-in tool, creates the Energy model, and sends it to the Cloud service Autodesk Insight that calculates Energy Use Intensity (EUI) measured by kW/m²/yr and the cost of consumption measured by Euros/m²/yr. The calculation provides a range of options for energy improvement goals with automatic consumption predictions calculated with Green Building Studio.

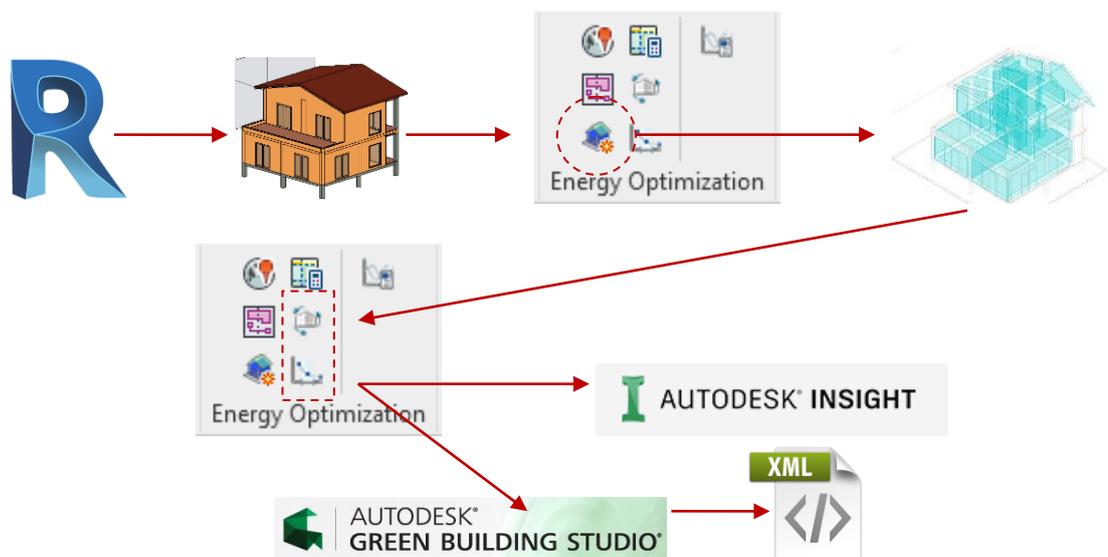


Figure 56 – Sequence for Energy Performance modelling, analysis and Cloud base evaluation

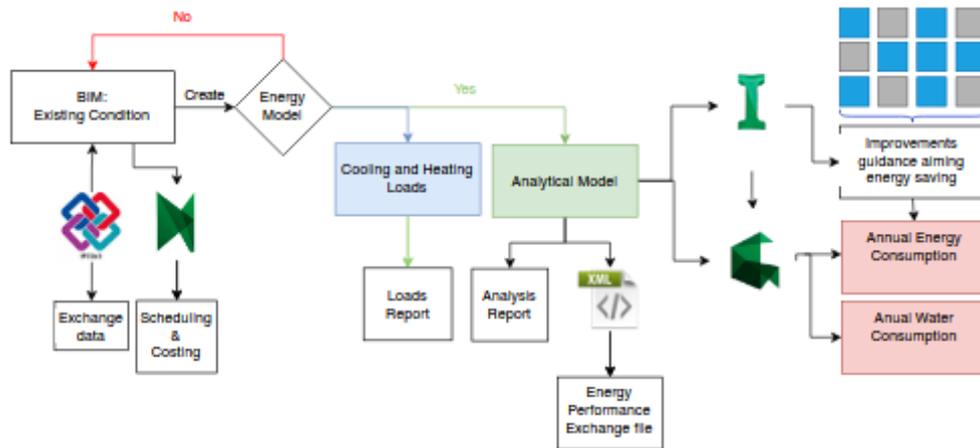


Figure 57 - The Revit-based sequence for an analytical model whose data is used in calculation environment GBSs for energy-related predictions

The optimization provided by Autodesk Insight is useful to study the impact of, among many possible improvements within the building, insulating walls and roofs as interventions that demonstrate to decrease the energy consumption rates.

The options on Insight goes simultaneously to Green Building Studio and it calculates the cost of energy and water based on the existing conditions of the model. The results are shown in the Table below, for As-Is model.

Table 3 – Annual and Life Cycle data | Consumption and Cost | As-Is model

Comparison item	Existing Conditions
EUI Energy use intensity (MJ/m²/year)	1561,0
Annual energy consumption (kWh)	43605,00
Annual Energy Cost	10465,20
Life cycle energy (kW)	1308141,00
Life cycle cost	313953,84

Data input and results in One Click LCA– Existing conditions

The chosen method for carbon emission calculation uses the add-in which connects the virtual environment of One Click LCA to the material quantities acquired from the geometric model.

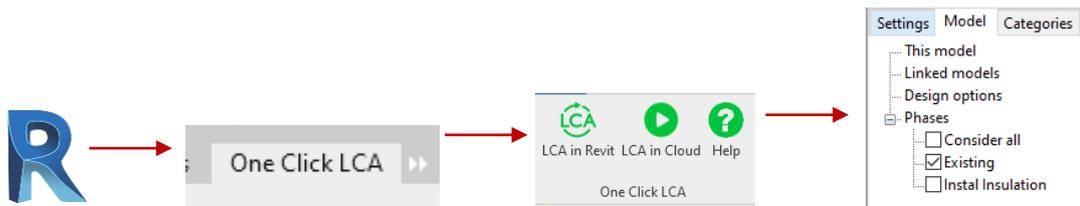


Figure 58 – Sequence to access LCA’s workflow and map materials according to model’s Phases

The Categories existing in the model are shown according to the image below. When unchecking Categories, their materials won’t be made available for mapping on the Materials tab.

Category	Included	Unit	Split objects to materials	Count
> Ceilings	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	7
> Doors	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	13
> Structural Framing	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	17
> Generic Models	<input type="checkbox"/>	Volume	<input type="checkbox"/>	16
> Floors	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	11
> Windows	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	10
> Walls	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	45
> Structural Columns	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	28
> Roofs	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	3
> Specialty Equipment	<input type="checkbox"/>	Volume	<input type="checkbox"/>	21
> Structural Foundations	<input checked="" type="checkbox"/>	Volume	<input checked="" type="checkbox"/>	2
> Curtain Wall Mullions	<input type="checkbox"/>	Volume	<input type="checkbox"/>	66
> Railings	<input type="checkbox"/>	Volume	<input type="checkbox"/>	5

Figure 59– Add-in window showing the identified categories that can be uploaded to the cloud calculation tool, no matter the Phase.

The materials tab breaks down the materials list to map them to the ones available on One Click LCA databases. They can be selected by dropdown “Data Source” icon, which allow selection of a database provided by the platform to select a material to map to. The filters provide a fast way to search for available materials by country, type.

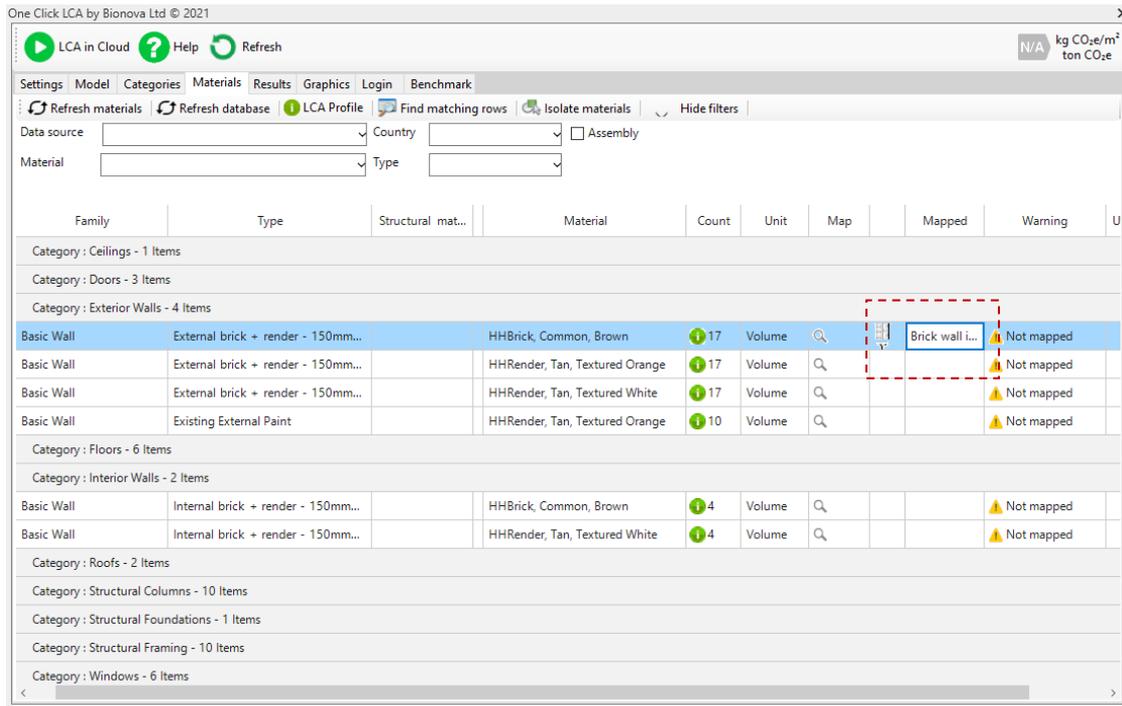


Figure 60– Add-in window showing only selected categories, no insulation types due to selected phase, and the mapping process before uploading to the Cloud for calculation.

One-Click LCA results – Existing conditions and embodied and operational carbon calculation

The calculation tool processes the amount of material pulled from Revit, connecting the area/volume to the mapped material carbon related data acquired from the EPD or generic materials assigned, and calculates material-related carbon emissions, without Operational carbon. The carbon calculation exposes the total amount of carbon-related to materials and breaks down the value between the components of the uploaded structure.

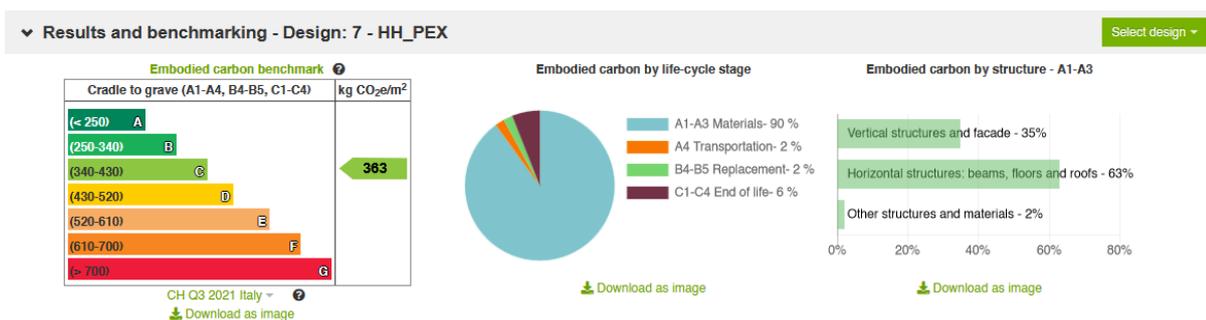


Figure 61 - Results for embodied carbon of the existing building

The highest concentration of CO₂ among them relates to the structure composed of concrete, known to be highly emissive due to its manufacturing process.

To generate the virtual calculation of life cycle carbon, the operational value related to energy consumption needs to be included in the tab (as water, if existing). Also the building area an calculation period are needed to the whole life cycle calculation.

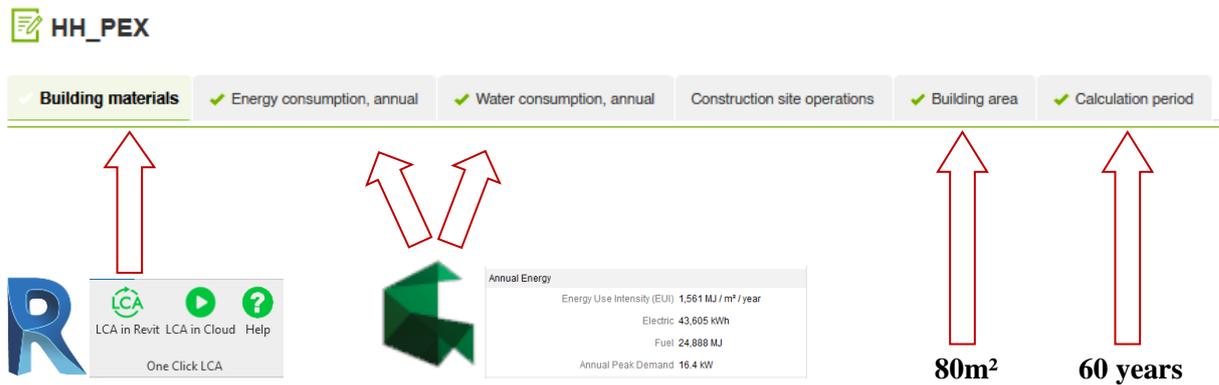


Figure 62 – One Click LCA tabs for data input, and data sources | Study Case

7.3. Creating the Insulated Model:

There are two ways of performing the LCA calculation for insulation phase. They vary according to the availability of material assigning validity on the One Click LCA add-in in Revit. The add-in doesn't save material mapping, which means that if the file is closed, it will be necessary to map again. The cloud platform, on the other hand, allows design data to be copied to other design, order to prepare the copied data for update, performed by the Revit add-in. For the LCA for each insulation type, the As-Is materials are considered to be reused, locking up the existing embodied carbon. To perform that task, the existing calculated design is copied in the LCA platform, its name is updated and the materials that's shall remain need to be assigned as reused, as chow in Figure 41.

After assigning the next phase, the selection of categories and material mapping performed according to Figure 57 and Figure 58 allows mapping the included materials and ipload to the cloud.

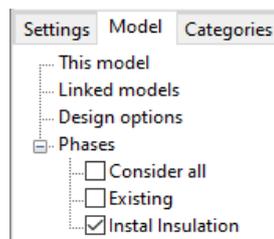


Figure 63 – Sequence to assign LCA's database materials to Phase Insulation

For every insulation type created in Revit, the content of a previous insulated design is copied into a new one which will be updated with materials quantities and new additions using the add-in.

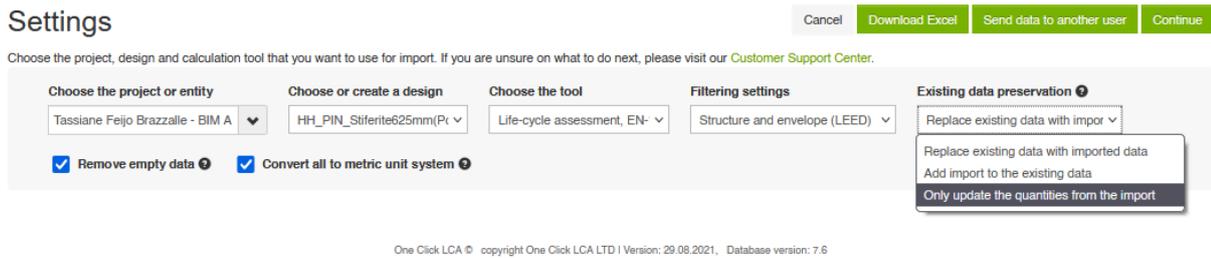


Figure 64 - Update an existing design

The results acquired by the virtual calculation tools needed to perform the LCA by insulation types modeled in Revit, are exposed in the table below. The values highlighted represents the best results by parameter, demonstrating that the best option of one of them does not fulfill the general needed benefits. The dependency between values urges designers to demonstrate their differences and, in the case of nZEBs, the impact on the energy consumption cost during the life cycle.

Table 4 - Insulation material general comparison

Material Parameter	Existing Conditions	Rolan Rock Wool	Mètisse Recyc. Cotton	Freude nberg Recyc. Plast.	Isol confort EPS	Stiferite EPS
Width (mm)	150	150+51=	150+100	150+100	150+100	150+62,5
λ W/mK	0,577	0,0368	0,039	0,033	0,031	0,022
Wall R m²K/W	0,26	1,646	2,824	3,29	3,486	3,078
Wall U W/(m²K)	0,342	0,331	0,240	0,216	0,206	0,225
An. Energy Cons. (kW)	43605	21480	19923	19657	19571	19836,0
An. Energy Cost (€)	10406,20	5155,20	4781,52	4717,68	4697,04	4760,64
Life cycle En. cons. (kW)	1308141,0	644414,0	597698,0	589718,0	587122,0	595095,0
Life cycle En. cost (€)	313953,84	154659,36	144447,52	141532,32	140909,28	142822,80
Total Mat.	0	732,66	435,93	818,64	1539,87	922,15

Cost (€)						
GWP	100%	48,21%	44,53%	44,21%	43,86%	46,05%
AP	100%	48,85%	45,09%	44,74%	44,26%	45,45%
EP	100%	48,84%	45,16%	44,83%	44,24%	45,83%
ODP	100%	48,58%	44,95%	44,79%	44,09%	48,47%
POCP	100%	47,38%	43,26%	43,02%	42,45%	44,74%
Total use of primary energy	100%	49,03%	45,17%	45,17%	44,47%	45,97%
Bio-CO2 storage	100%	30,24%	11,88%	2,19%	2,19%	36,29%
LCA - EN 15978 (kg CO2e)	1370033	660574	610099	605709	601029	630966

7.4. One Click LCA results

The calculation environment of One Click LCA shows results interactively and comparatively, according to the number of design. The tool updates according to data input, the more intensively developed the model, the better and most assertive the results will be. The baseline is the existing building (HH_PEX) with the 100% value of GWP emissions. The graphs depicts each impact by materials

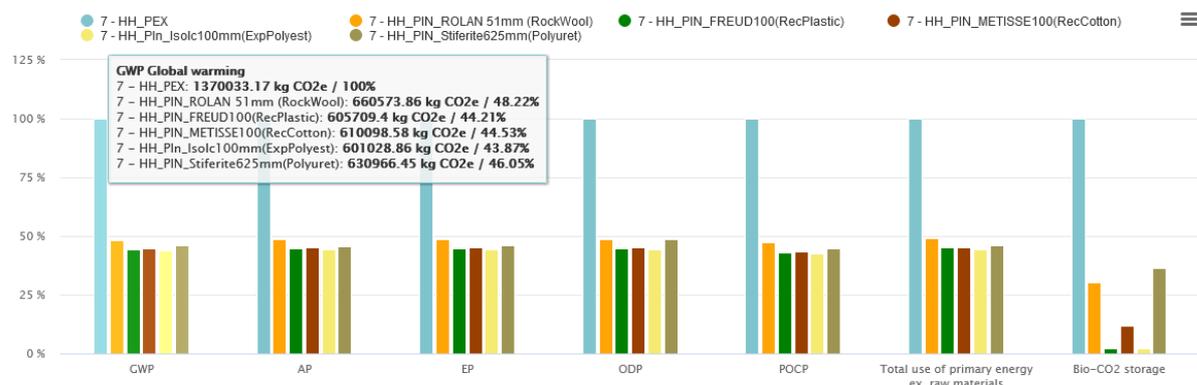


Figure 65 - LCA, EN-15978 - All impact categories

The Bio-CO₂ Storage indicator shows the trapped CO₂, the amount of carbon retained during the service life of the material. The highest the column, higher is the amount of carbon that will be released once the service life of that material reaches its end. This indicator shows that materials with recycled content are the least emissive, since the quantities and origin of used material connect to circularity, and avoidance of raw material consumption. The three recycled materials have the same width but different density, data provided by the mapped EPD together with the material volume retrieved from the model. The connection between these data provides a visual of the impact.

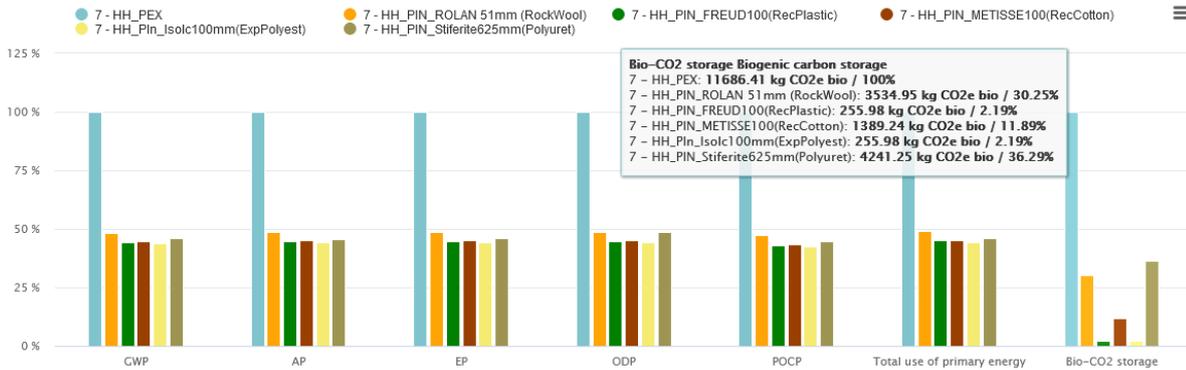


Figure 66 - Life-cycle assessment, EN-15978 - All impact categories | Bio-Co₂ comparison

Also, the environmental impact of material manufacturing is showed when isolating the category. The framed ones in Figure 65 are insulation based on recycled materials, with different densities. The absence of raw materials and the inclusion of recycled processes to generate new construction products decreases the emissions related to phase A1-A3. These materials have similar carbon emission values for maintenance and replacement, interventions on those during this phase might be for a balanced B1-B5 strategy. Once the service life of these materials are over, they can be recycled again, but at a different environmental cost during phase A1-A3.



Figure 67 - LCA, EN-15978 - Global warming, kg CO₂e - Life-cycle stages – Embodied carbon by material type

The Figure 66 shows that the emissions related to energy consumption decrease more than 50% only by implementing insulation solutions to the envelopes components. The material that emits the lowest amount of carbon due to its origin (recycled) does not perform so well related to energy savings. It would need a thicker width to increase its performance, which would be acceptable in terms of recycled material, but increase the expenses related to B1-B5.

The figure below shows that the emissions related to energy consumption decrease more than 50% only by implementing insulation solutions to the envelopes components.

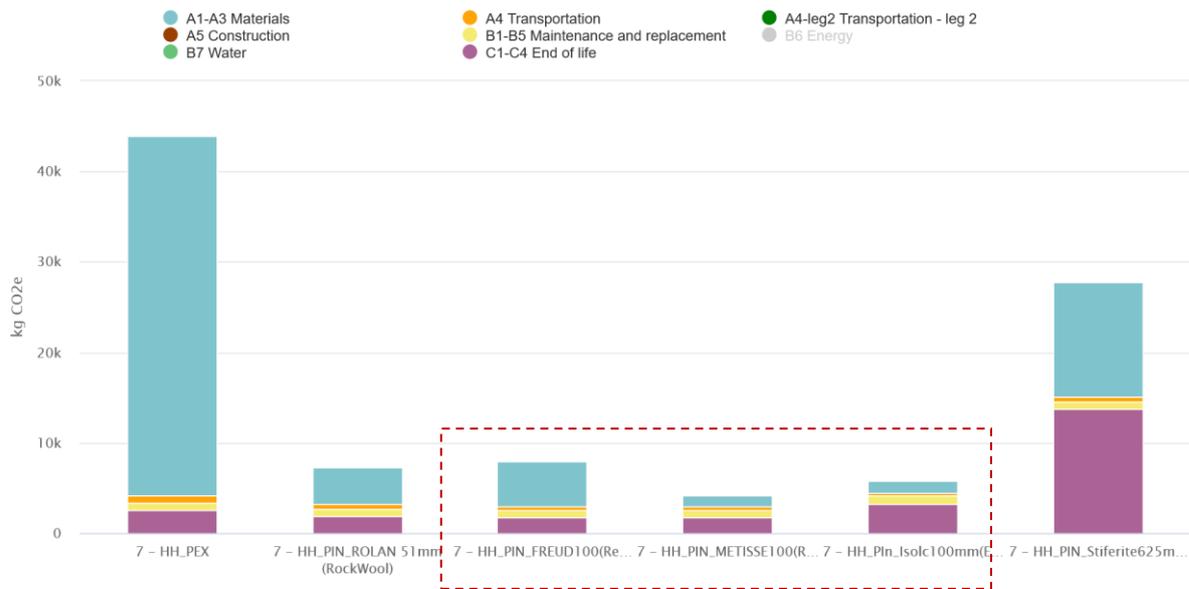


Figure 68 - LCA, EN-15978 - Global warming, kg CO2e - Life-cycle stages, without energy value

The material that emits the lowest amount of carbon due to its origin (recycled) does not perform so well related to energy savings, shown below. It would need a thicker width to increase its performance, which would be acceptable in terms of recycled material, but increase the expenses related to B1-B5.

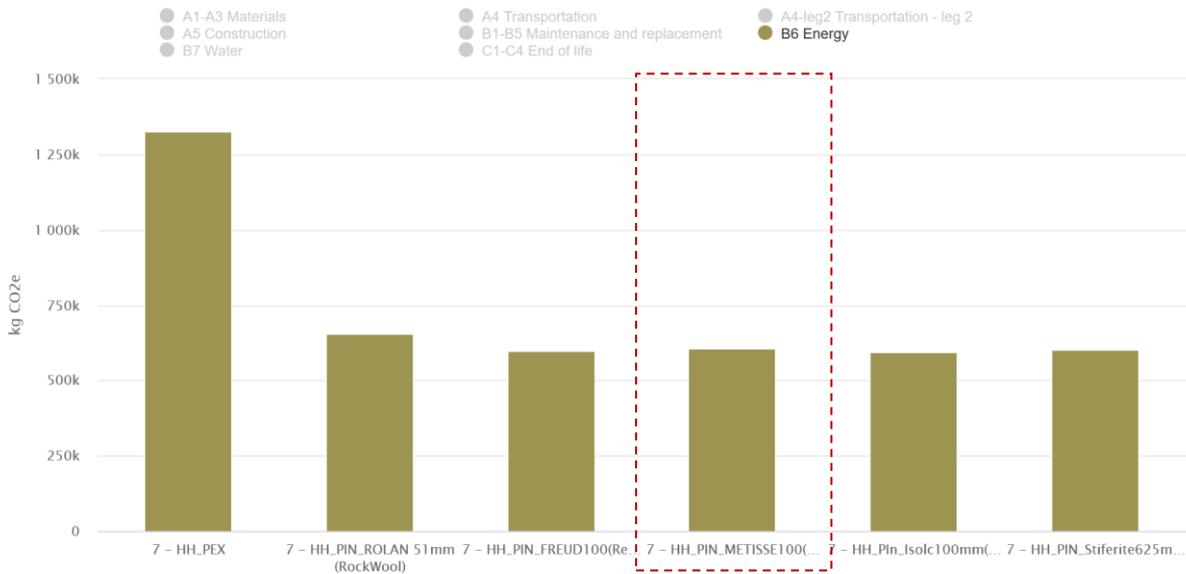


Figure 69 – GWP Life Cycle Stages – only energy

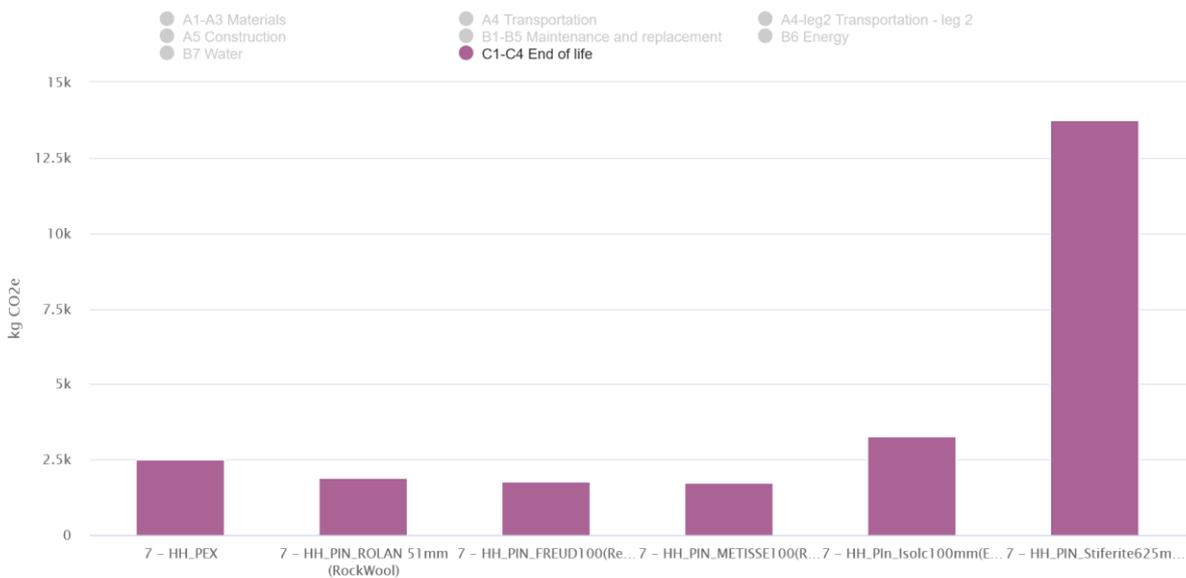


Figure 70 – The impact of decommissioning and deconstruction, by material

One Click LCA demonstrates carbon emission calculation in several different and interactive ways, by accessing the platform. The evaluation of each individual result allow decision making based on the environmental impact of each chosen material.

8. CONCLUSIONS

Developing a BIM for refurbishment works depends highly on the quality of the existing acquired data. These data needs to be included in the model by the means of parameters to export or connect to other software, update whenever needed and using BIM as a repository. The BIM retrieves data related to demolition, reconstruction, the inclusion of new acquisitions, adding cost information to all kinds of intervention. These data are useful for planning the continuous use of an existing building providing static information for its operation scheduling aiming maintenance, replacement, predicting their general cost, and related consumption. The BIM provides scheduling the existing amount of material if correctly modelled, and associates information restrictions and rules possibly applied to the existing building.

Developing a multi-phased model allows a controlled way to get materials quantities before and after any intervention. Creating different family types with specific thermal properties for insulation evaluation is useful for performance calculation by material. The results acquired after connecting the BIM material quantities and energy calculation values depict the implication of adding layers and demonstrates the energy consumption rate changing according to materials performance data applied for each created type, perceived on the Annual Energy Consumption Calculation results calculated with Green Building Studio.

The model for building performance calculation requires the thermal properties of the materials to be included in types. The standard Revit material's thermal values are not reliable due to the way the software performs the calculation, which is hard and not clear to interfere with. On the other hand, including external calculated thermal data in a specific section of types properties had an impact on the energy calculation, which demonstrates the possibility of using it. Using Microsoft Excel allows the investigation of the relationship between materials that calculated with equations. The results were added to the model, in the specific parameters fields, manually and/or with the help of third-party software like DiRoots SheetLink.

The life cycle assessment for an existing building, performed in a calculation virtual environment depends directly on the quantities and type of each material, retrieve by the BIM. Material's carbon emissions calculates over its mass (m² or volume). The use of BIM for this task is strategic by easily quantifying the virtual object's mass and transferring it to the cloud by dedicated add-ins.

The LCA tool, One Click LCA, is enriched by material and products databases aiming at sustainability. Its use for the existing building's assessment is tricky due to the high performance of the material options within the databases. Since mapping a database material to those existing in the model is mandatory for the virtual calculation, the conditions of an existing building may not correspond to the options provided by the tool. The existing building structure and envelope materials when considered as reusable, during the calibration of material input, demonstrate a decreased environmental impact almost by half since B1-B5 are still considered for existing structures. The chosen materials for the existing building's carbon emission calculation were the basic as possible, leaving for the refurbishment materials to demonstrate the power of the virtual calculation by choosing

better performance materials with recycled values included and understand the impact of choosing innovative ones, reducing the carbon footprint for the life extension of the asset.

The LCA platform connected to the BIM model without the use of exported files allows designers to save time by assigning database materials thru industry impact reports - EPDs - to BIM the model materials. Since the EPD data is stored in the LCA databases, mapping BIM material to an EPD provides the carbon emission calculation according to material calculate area/volume. By replacing mapped materials in the calculation environment in the Cloud updates the carbon calculation instantly. But if the quantities of the BIM model change or if the material unit's dimensions is different than the modelled one, the calculation will be one, but they won't be correct. It is also possible to update manually area and width (volume) in the Cloud-based platform, but this method amplifies the chances of human error.

The attempt of calculating LCA exported green building structured file (.gbXML) was not successful, since the platform did not recognize the materials named in the model. Instead, the automatic identification of the materials highly increased the quantity of one specific kind of material. This attempt, if followed, would need a high manual verification.

Choosing the materials to perform Life Cycle Assessment for the refurbishment phase had a purpose, to assign high-performance ones based on thermal transmittance information provided by EPDs. The high-performance materials shown to contribute to a lower energy consumption, which decreases the carbon emissions related to energy use (B6). Recycled materials didn't perform so well in energy use (stage B6) but decrease radically the carbon emissions related to stage A1-A5. Commonly used high performance expanded insulation material also contributed to decrease stage B6 carbon emission rate but it has high emissive impact related to material emissions shown in stage A1-A3, and the emissions related to the end-of-life on stage C1-C4 are also high, due to their composition and method of discard.

The results calculated with One Click LCA acquire by connecting material quantities (calculated by modelling in Revit), adding annual energy consumption (calculated with Green Building Studio), and renewable sources generation (calculated with PVGIS), provides a cloud-based comparable and fast way to evaluate options for materials decision over the best strategy to reach the nZEBs. The implication of including energy consumption values combined with calculated renewable generation does not decrease the carbon emission impact of energy consumption but includes the carbon emission avoidance represented by renewables generation as a positive and beneficial implication informed in stage D of the life cycle assessment.

The virtual calculation tools retrieves independent results and as a consequence the several data sources need to be read all together to compare material's performance, consumption and costs and make decisions based on requirements and stakeholders expectations.

Finally, the proposed process does have a level of automation started by the authoring tool and finished when energy and water calculation are done, with the chosen tools (Revit and Green Building Studio). Working with several data sources requires an organized and systematic sequence providing an easy allocation of results for comparison goals. The BIM needs fair development based on industry

best practices related to classification, used in the calculation environment importing process. To simulate the operational carbon after improvements, the energy consumption needs proper calculation in a dedicated environment so the results included in the LCA tool are reliable. Data manipulation skills are essential for data comparison when the used virtual calculation tools cannot show all relevant fields.

As suggestions of future work are the massive inclusion of computational design to enrich the model, export the necessary data, and including information from the several sources into the carbon calculation tool. Programming skills should be used to connect cloud-calculation results directly on management platforms.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACER	Agency for Cooperation of Energy Regulators
AEC	Architecture, Engineering and Construction
API	Application Programming Interface
BCF	BIM Collaboration Format
BEM	Building Energy Modelling
BEP	BIM Execution Plan
BIM	Building Information Modelling
CDE	Common Data Environment
CMP	Conference of the Parties
CVE	Calculation Virtual Environments
EGD	European Green Deal
EPBD	European Performance of Buildings Directive
EPD	Environment Product Declaration
EU	European Union
GBS	Green Building Studio
GHG	Greenhouse Gas
GWP	Global Warming Potential
HVAC	Heating, Ventilating and Air Conditioning
IEA	International Energy Agency
IFC	Industry Foundation Classes
IFD	International Framework Dictionary
LOD	Level of Development
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MREPD	Machine Readable EPD
NZEB	Nearly-Zero Energy Buildings
nZEB	Net-Zero Energy Buildings
O&M	Operation and Management
PEB	Positive Energy Buildings
P.Ex.	Phase Existing (Revit 2021)
P.In.	Phase Insulation (Revit 2021)
SaaS	System as a Service
SDG	Sustainable Development Goals
UN	United Nations
US EPA	US Environmental Protection Agency
WGBC	World Green Building Council
ZEB	Zero-Energy Building

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APPENDIX

APPENDIX 1: STUDYCASE STRUCTURE

