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LCA-based strategic evaluation for building renovation construction projects

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Abstract. It is well known that the existing building stock needs performance upgrades related to energy retrofit. In Italy and many European countries seismic structural safety standards requirements are also increasing, and therefore together with other renovation works, a structural rehabilitation is always needed. Structural rehabilitation is generally an invasive intervention on the structural sub-system, while energy redevelopment is less invasive as it is mostly performed in the building envelope, but it is economically relevant. Therefore, the high renovation costs and the limitation of the usability of the building during a renovation project often lead real estate developers to choose the easier strategy of complete demolition and reconstruction. This can be, perhaps, the easiest choice but, from an environmental and economic point of view, usually the least sustainable one. Environmental sustainability can be evaluated via the Life Cycle Assessment (LCA) approach, but LCA needs a complete evaluation of the existing and new building systems, sub-systems and components. Therefore, the strategic choice based upon LCA can usually be performed only late in the design process, when most of the technologic systems have been designed in detail. A parametric preliminary evaluation can help project managers and real estate developers to choose the most environmentally sustainable design alternative, even with a low level of knowledge of the existing building. The proposed approach uses a list of parametric costs for a building type to extract preliminary data about building quantities. Therefore, a mixed method that uses typical cost plans and existing LCA database is proposed to perform the preliminary LCA analysis of a building renovation project and evaluate sustainability.

1.Introduction

It is well known that the existing building stock needs performance upgrades related to energy retrofit. In Italy and many mediterranean countries also seismic structural safety standards requirements are increasing and therefore, together with other renovation works, a structural rehabilitation is always needed. Construction operators are getting more and more involved in the debate concerning the strategic choice between demolishing and rebuilding, or alternatively renovating and recovering existing residential buildings. These two strategic alternatives, aimed at urban regeneration at the building level, have been considered for decades, at the national and the international level [1]. The actual dilemma of real estate developers is whether the demolition process and the consequent reconstruction of a building, creating a new system with increased structural and energy performance levels, is more sustainable in terms of environmental impact than the renovation and performance implementation of the same building. The scientific evidence in favour of one or the other approach is still under discussion and indeed still affected by uncertainty [1], as it is linked to constraints and conditions of within the specific context. Sustainability in the construction sector is subject of particular attention as it is attributable to a high share of environmental impacts. Buildings constitute a large consumption of raw materials, energy consumption, pollution emissions, waste production both in the construction phase, in the use and maintenance phase, up to the demolition or renovation phase, as also indicated by the UN Agenda for Sustainable Development to 2030 "Sustainable Development Goals – SDGs", which indicates goal no. 11 "Make cities and human settlement inclusive, safe, resilient and sustainable" oriented to the pursuit of the sustainability of human settlements [2]. These settlements are also responsible for a large proportion of land use, and consequently the need for the transition to a more sustainable impact while safeguarding the objectives that Europe and the United Nations have set themselves to protect the environmental heritage and the landscape [2]. Although most of the energy use of an ordinary residential building comes from operational energy, embodied energy of building is a significant share of global energy use of a building [3], and consequently carbon emissions. Recent research has given evidence of the great portion of embodied energy in an average life-cycle of a residential building. The embodied energy of a conventional building could account for the 38% of the total life cycle energy use and this part can increase up to the 46% for a low energy building [4] [5]. Therefore, the debate about the decision between the two different strategies, retrofitting and demolition versus reconstruction needs to be focused. Pittau et alii [6] in the Italian context of the retrofitting of industrial buildings, argued that new construction option has an higher impact to Global Warming than retrofitting alternatives, while green retrofitting can be highly conditioned by the choice of materials and challenges for decision making [7]. Alba Rodriguez et alii [8], added that retrofitting of is almost 66% less environmental impact than new construction. Despite the significant reduction in energy consumption compared to that of the original building, the demolition and the reconstruction processes create such an high impact that this kind of intervention remains unjustified. Life Cycle Assessment (LCA) is being increasingly applied in the construction sector to assess building environmental performance [9] [10]. Building Life-Cycle is, actually, of capital importance as the two different strategies, demolishing and reconstructing or renovating and retrofitting have to be evaluated on a life cycle basis. LCA addresses the entire building life cycle, starting from raw materials extraction and processing, continuing with the production of building components, to the installation and transformation of building product on site, to the operation stage and the end-of-life and disposal. The ISO 14040 standard describes four stages of the LCA evaluation process: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and final interpretation. In case of LCA for buildings usually, many predetermined database have been developed and used, therefore LCI and LCIA are merged in one step and simplified [11]. Environmental sustainability can be evaluated via the Life Cycle Assessment (LCA) approach, but LCA needs a complete evaluation of the existing and new building systems, sub-systems and components, therefore, the strategic choice based upon LCA can usually be performed only late in the design process, when most of the technologic systems have been designed in detail. Nevertheless, a first strategic choice needs to be done by owners or real estate developers early in the design process. A preliminary LCA-based strategic evaluation can help project managers and real estate developers to choose the most environmentally sustainable design alternative, even with a low knowledge of actual building quantities. But this has a need of understanding and modelling existing building technology, even with few information based upon a quick survey. The proposed approach uses building parametric costs of typical buildings from literature to create a construction project cost plan and extract data about building quantities. Therefore, a preliminary LCA analysis of a building reconstruction or deep renovation project can be performed, and its sustainability can be evaluated.

2. Literature review

2.1 Building renovation vs. reconstruction and LCA

The theme of the comparison between the two building regeneration alternatives, i.e. demolition and subsequent reconstruction and deep renovation, has been analyzed by many scholars and AEC operators at least for for decades, but the scientific debate starts with the comparison between the embodied and operational energy use, and consequent greenhouse gas emissions. The total operational energy used by a building during its life cycle, for a life span of 50-100 years is because buildings use energy sources such as electricity and natural gas to heat, cool and light indoor spaces thus maintaining comfort conditions for the occupants [3]. Operational energy reduction can be achieved by energy efficient, net-zero or carbon neutral buildings. Embodied energy instead, is created while processing different construction materials in the construction stage, including materials' production and delivery to site, construction operations, maintenance, replacement and final demolition and disposal. Unlike operational energy use, embodied energy sources are many, such as electricity, natural gas, coal, petroleum products. Embodied energy may represent a great part of energy use in a low energy building life cycle. Multi objective optimization of design parameters and materials can reduce both embodied and operational energy and carbon emission [3]. Recent research has given evidence of the great portion of embodied energy in an average life-cycle of a residential building. Residential buildings can be categorized as conventional or non-conventional. A conventional building refers to a building built according to the common practice for a specific country within a specific period, while a low energy building refers to a building build according to special design criteria aimed at minimizing the building's operating energy [4]. The embodied energy of a conventional building could account for the 38% of the total life cycle energy use and this part can increase up to the 46% for a low energy building. Therefore, the debate about the decision between the two different strategies, retrofitting and demolition versus reconstruction can be tackled addressing environmental sustainability considerations [4]. The very first studies about the problem indeed, addressed the trade-off between renovation and reconstruction from the point of view of a value-based decision framework for private commercial properties. The objectives considered by Ohemeng [12] are both economic and financial, and based on a careful analysis of the needs of users. Therefore Ohemeng proposed to consider three categories of requirements in a value-based decision model: building space, internal environment and physical and structural requirements. After that, demolition and reconstruction is compared with deep renovation concluding that real estate developers are primarily concerned with economic and functional issues of the building. The seminal work of the US Army Corps of Engineers of 1999 [13] included environmental sustainability requirements, addressing reuse and recycling of materials from the demolition of existing buildings, but through a cost-benefit approach. The study highlighted that actual costs may depend on several variables: type and size of construction project; possibility of developing reuse of building materials based on site and operational constraints, , availability and capacity of recycling plants, construction project schedule characteristics, local taxes and economic constraints, working experience of laborers employed for demolition stage, and building block and urban context. After considering this, an environmental impact can be assessed based on an evaluation scoring matrix. The debate about building demolition and reconstruction versus redevelopment has been addressed by Power [1] indicating the following benefits of building renovation: conservation of the existing ownership structure, benefits on the built context because of the image of renovated buildings, speed of project execution and therefore less inconvenience for occupants.. Because of this, building redevelopment should be encouraged by state incentives, in particular addressing energy efficiency of buildings. Building environmental sustainability has been addressed by many scholars from a life cycle, cost or assessment perspective. Guardigli, Gulli and Mazzoli [14] analyzed the case study of the regeneration of the recent Italian residential building stock with the global cost approach, indicating that the success of renovation projects depends on a context-based positive environment. Fiore, Donnarumma and Sicignano [15] indicated that there are multiple variables to be considered in the evaluation of renovation projects, environmental sustainability, structural safety, durability, service life and economic aspects, proposing a Multi-criteria evaluation that uses the Analytic Hierarchy Process method. Concerning the Pro-Get-One case study, Guardigli, Bragadin, Ferrante and Gulli [16] compared Life Cycle Cost Analysis with Life Cycle Assessment, in a life cycle planning perspective for the various possible design alternatives needed to upgrade energy and structural performances of residential buildings, with the construction of an external superstructure, exoskeleton, with energy and seismic requalification functions. Later, Bragadin, Guardigli, Calistri and Ferrante [17] compared the LCA estimate for the same case, the Pro-Get-One refurbishment project, that was performed in Concept Design Stage (CDS) and in the successor Technical Design Stage (TDS), arguing that LCA estimate in the CDS is of capital importance to select the chosen design alternative, but it can be affected by a large range of error. Concerning both types of building renovation, the energy oriented and the structural safety oriented, that are often the cases of Italian and South-European deep renovation projects, Artino, Caponetto, Evola, Margani and Marino [18] proposed a decision-making analysis tool addressing the envelope and the load-bearing structures of reinforced concrete conglomerate. The proposed system takes into account the existing energy and structural performances, project total cost and duration, environmental impacts and the disturbance to the occupants. In the case of Post-Earthquake reconstruction, Bratti and Bragadin argued that LCA analysis needs to be included in a broader Multi-Criteria Analysis to detect the most suitable solution [19]. However, green building design decisions should be driven by energy efficiency rating and carbon emissions accounting [20]. Thibodeau, Bataille, and Sie [21] indicated that LCA methodologies provide most of building environmental assessment information for building renovation projects, while Ismaeel and Ali [22] addressed the environmental assessment of deep -renovation projects for the "Richordi Berchet" historic building pilot study. The study compared green building rating systems such as the Leadership in Energy and Environmental Design (LEED) system with environmental assessment methodologies as LCA. In the case of Italian industrial building renovation projects, Pittau et alii [6] argued that new construction option has an higher impact to Global Warming than retrofitting alternatives, while green retrofitting can be highly conditioned by the choice of materials and challenges for decision making [6] [7]. A similar conclusion was found in another South European country, Spain, by Alba Rodriguez et alii [8]. In the Spanish pilot case they found that retrofitting was almost 66% less environmental impact than new construction and despite the significant reduction of energy consumption of the reconstructed building compared to that of the original one, the demolition and the reconstruction processes create such an high impact that reconstruction cannot be considered as sustainable in the short term. Finally, Costantino, Benedetti and Gulli [23] addressed the issue of circular economy in the construction sector by application of digital twin strategy as a decision making tool to regenerate urban suburbs. Therefore, environmental requirements are of capital importance to detect the required level of building performance of building life cycle duration needs to be assesed in a sustainability perspective. The most common methodologies to perform an Environmental Performance Evaluation (EPE) include the followings: Environmental Indicator Systems, Environmental Management Accounting and Systems, Life-Cycle Analysis (LCA) and Eco-labelling [24]. As a matter of fact, ISO standards of the 14000 series cover all of them. The Life Cycle Assessment is the most comprehensive, because it is based on the sustainability assessment of the whole life cycle of products, from production to disposal, and include all the possible physical impacts on the global ecosystem, as well as the aggregation of all of them to create a complete Decision Support System (DSS). LCA is an internationally recognized approach to evaluating the potential environmental and human health impacts associated with products and services throughout their life cycles. LCA examines indicators within four environmental impact categories, including climate change, human health, ecosystem quality, and resource depletion. Life Cycle Assessment approach, basing on ISO 14040 [25], can be used to perform a broad evaluation of all different environmental impacts of construction and building - related processes in every design and construction stage [17]. The evaluation of each design alternative by means of LCA analysis allows designers to choose the most suitable solution to decrease Green House Gas (GHG) emissions in the atmosphere and reduce damages to the environment and the life of human beings because of the emission of pollutants and natural resources depletion. Environmental LCA is a well-known assessment technique that evaluates environmental performance of a product, a process or a service via the quantification of the extraction and consumption of resources, including energies, and the related emissions to air, water and soil in every life cycle stage. The aim is to detect the potential contribution of the production processes to the environmental impact categories [26]. LCA analysis requires the definition of the system functions, of the functional unit and system boundaries [25]. In case of building renovation projects, in the Italian context, the system functions can be defined by the Italian standard UNI 8290-3, while the functional unit indicates the measurable unit that is taken as a reference for input and output data. Concerning system boundaries for a building project, the whole building life cycle is addressed (from cradle to grave). There are three main stages in the life cycle of a product: pre-use; usage and end-of-life, i.e. from raw materials extraction, production of building components, transportation, on site installation, operation and maintenance, demolition and disposal of waste (and eventually re-use i.e. cradle to cradle) [26]. The life Cycle Stages, according to standard EN-15978 considered in the following pilot study are A1 – raw material supply, A2 transport, A3 Manufacturing (Product stage) and A4 transport to building site and A5 installation into building (Construction stage) [27].

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2.2. The Italian existing building stock: strategic choices for energy and structural deep renovation and LCA evaluation

Recent statistical surveys carried out in Italy regarding the characteristics of the national building stock to determine its vulnerability to climate risks - but the same situation could affect many European countries - show that the residential building stock represents approximately 85% of the overall stock. Based on data gathered by CRESME Information System [28], in Italy 12.5 million existing buildings were mapped in 2022. Among these, more than 7 out of 10 are over 40 years old, 7.5 out of 10 are single-family buildings, but above all, almost 2 out of 10 are in a very bad state of conservation. These three characteristics highlight that the building stock is highly vulnerable to extreme events: their age does not ensure construction techniques capable of guaranteeing adequate resistance in the event of an earthquake, a vulnerability amplified by the poor state of conservation. Jointly, in recent decades, energy efficiency and environmental sustainability have taken on a central role first in the design and construction of new buildings and soon after also in the retrofitting of existing ones. Attention has shifted towards reducing energy consumption and CO2 emissions, with the aim of creating healthier and more comfortable environments for occupants. In this context, the reuse and retrofitting of existing buildings seems to be a winning solution, capable of combining the conservation of architectural heritage with the adoption of innovative technologies. Certainly, the reuse of existing buildings represents a sustainable approach to meet new functional and environmental needs as an alternative to demolition and reconstruction. This approach allows for reducing the environmental impact linked to the production of new construction materials and the management of waste resulting from demolition. The retrofitting of existing buildings, however, focuses on reducing energy consumption and improving environmental performance. This can be achieved through targeted actions, such as thermal insulation, the installation of photovoltaic systems and the use of energy management systems. Retrofitting can also involve reducing the environmental impact of buildings using eco-friendly materials and promoting sustainable construction practices. An American group of experts, the Preservation Green Lab [29], recently published research defining that the retrofitting of existing buildings is much more sustainable than the demolition and reconstruction of new green buildings. Six building types were examined by the research, all buildings located in four different climate situations: Phoenix, Chicago, Atlanta and Portland. The building types vary from commercial offices, warehouses, and elementary schools to single-family and multi-family homes. The retrofitting of existing buildings for each of these categories appears to produce less environmental impact than the construction of new buildings to take their place. This is because, despite the energy performance, it takes at least 80 years to offset the environmental impact of the new construction. Utilizing a Life Cycle Analysis (LCA) methodology, the study compares the relative environmental impacts of building reuse and renovation versus new construction over the course of a 75-year life span. According to this study, therefore, in most cases, an old building that is renovated has a lower impact on the environment than the construction of a new building that replaces it [29]. By analysing the procedures taken in this study, it is important to consider that the American building stock is very different from the Italian one (or the Mediterranean one, in a broader sense) in terms of age, construction practices and state of conservation. Therefore, the necessary interventions have a reduced impact on buildings. But a key aspect to add to this study would be to increase structural safety too, as a contingent need for Italian local heritage. Research, in this sense, is much smaller as generalizing the results becomes more complex. In fact, if the aim is to focus interventions related to energy efficiency, these can be classified as repeatable and recurring: insulation of the whole building envelope, replacement of fixtures, and improvement of plants and systems. The materials may vary, but the categories of intervention do not. Structural strengthening, however, is difficult to define as recurring, as the variability in terms of materials of the load-bearing structure (reinforced concrete, unreinforced masonry, timber or steel), the different structural layouts and the different performance levels to be achieved based on the construction area and functions of the building, lead to non-standardizable intervention solutions. The materials for structural strengthening are yet not sustainable, having to guarantee high resistance values: steel, reinforced concrete, reinforcing fibres, and cement-based materials are not among the materials with a high degree of sustainability, as they have high environmental and energy costs. Therefore, a deep renovation project that aims jointly at energy retrofitting and at structural strengthening, may not adhere to the the previously described research work

[29] , i.e. that in terms of environmental impact the demolition and reconstruction solution could be more sustainable. As just highlighted, defining generalizable solutions in this sense is complex, but a targeted investigation on specific building types may be indicated to deduce the first results.

3. Materials and methods: Life Cycle Assessment in the preliminary design stage

3.1 Life Cycle Assessment and the ISO 14040 standard methodology in the Preliminary Design Stage (PDS)

The Life Cycle Assessment (LCA) method was chosen by many authors addressing the problem of sustainability of building renovation projects because sustainability is understood as environmental quality, and a result of a global process that integrates all the phases that constitutes the entire life of a complex system such as a building. LCA methods in fact, use a rational approach that changes and evolves by acquiring knowledge, and in this way it can affect new technologies because it allows to evaluate their impacts in advance [17]. The Life Cycle Assessment - LCA methodology was codified by the ISO 14040:2006 standard and is defined as follows: "Objective environmental assessment technique for the qualification of the environmental impacts of a product or process during all phases of the life cycle, through the systematic measurement of all physical exchanges to and from the environmental system" [25]. This is the innovative concept of LCA, any hypothesis of change and/or improvement of the system under study can be evaluated totally, addressing the impact of the whole life -cycle of the building product or process. The different building life cycle stages that must be considered for the LCA-based environmental assessment are the manufacture of the components, the construction, the use of the building, the renovation and renewal of the components, the final dismantling and treatment of the various components after dismantling. It must be considered that for the LCA-based building sustainability analysis, only the impact of the building on the global environment and ecosystem is considered, while the aspects related to the internal comfort are generally assessed by other methods and tools. In the following building case study, which aims at comparing the LCA estimate of a same type of building in both hypothesis of redevelopment and of demolition and reconstruction, the same level of internal building comfort after construction / renovation project execution is one research work assumption. As known, the structure of the LCA methodology proposed by ISO 14040 is divided into 4 phases: 1: Global and Scope Definition; 2: Life Cycle Inventory analysis (LCI), 3: Life Cycle Impact Assessment (LCIA); 4: Life Cycle Interpretation (fig. 1) [25].

1. Global and Scope Definition

The starting point is the definition of the objective and scope. In this stage the objective to be focused are the field of application, the product to be studied and all the needed process units within the life cycle of the product. According to ISO 14000 standards the scope of the LCA analysis must include the following: product system(s), in case of comparisons; functional units; system boundaries; selection of the impact categories to be taken into account;and the final impact assessment and interpretation methodology. The definition of the boundaries of the system under evaluation is of paramount importance, as can change considerably the final results, depending on the study objectives. Changing system boundaries indeed, cause inevitably a change in results. The definition of the system boundaries must consider the main stages of the life cycle, the processes and the flows of energy and materials that condition them. Another important definition to be set is the functional unit of the analyzed product. The functional unit identifies the qualitative and quantitative aspects of the product, service or function under analysis and is the reference unit for measurement of all incoming and outgoing flows and data. Therefore, the Functional Unit is of primary importance to provide comparable results of Life Cycle Assessment, even in case of evaluation of different systems [17] [25].

2. Life Cycle Inventory analysis (LCI)

Inventory analysis consists of the actual collection and quantification of incoming and outgoing flows of materials, energies, and environmental impacts of the product system under evaluation. LCI also provides structure and organization of this data according to the model assumptions of the entire life cycle of the system. The objective of this stage is to quantify and compute all the needed input raw materials, the waste output and the estimation of energy , soil and water consumptions throughout the life cycle of the system. All data must refer to the functional unit. Input and output data can be retrieved through literature studies, books, government documents, statistical sources, technological or market

database. In the following case study, datasets from literature studies, including the use of a specific dataset of a software package were used [17] [25]..
3. Life Cycle Impact Assessment (LCIA)
In this stage the starting point is from the results obtained from the previous life cycle analysis stages. Now it is possible to proceed to the analysis of the impacts on human health and the environment, based on specific LCA indicators. These environmental and health impact indicators are based on scientifically valid data, shared by the international scientific community and applicable in the proposed case study (table 1) [17] [25] [27] [30].
4. Life Cycle Interpretation
After LCA indicators estimation it is possible to proceed with the LCA interpretation and possible improvement, thus allowing to correlate the inventory analysis data with those of impact analysis. In this stage it is possible to obtain actual LCA results from useful and scientifically demonstrated considerations, directly related to the study objectives. The interpretation process is necessarely iterative, because it is the result of data depending on many variables that can be reviewed with the aim of improving LCA outputs and results for the product system [17] [25].
Therefore, environmental sustainability can be evaluated via the Life Cycle Assessment (LCA) approach. This implies that all the design strategic and technical choices are made, and this design process is usually completed only late in the design phase, when all the building technological systems have been designed in detail. LCA needs a complete evaluation of the existing and new building systems, sub-systems and components, so it can be properly performed only in the Technical Design Stage (TDS) [17]. The proposed LCA approach evaluates impacts of a building construction process in the Preliminary Design Stage (PDS) as to give to decision makers a support system to detect the most sustainable project strategy between the deep renovation vs. complete demolition and reconstruction. A parametric preliminary LCA evaluation can help project managers and real estate developers to choose the most environmentally sustainable design alternative, even with a low level of knowledge of the existing building. The proposed LCA evaluation approach for the identified case study, includes the following assumptions: the impact concerns only the greenhouse gas emissions, , the functional unit adopted is 1 m^2 of Gross Floor Area. Concerning inventory analysis, the database of a parametric public price list was used to detect material quantities, and the related GHG emissions were estimated with a commercial software, OneClick LCA®. Therefore, the impact analysis has been evaluated and discussed (fig. 1).

Table 1. Environmental indicators used to express the results obtained through the application of the LCA methodology.

Impact Indicator	Impact Category	Description	Units of measurement
TPES	Total primary energy usage	Consumption of non-renewable energy resources	[MJ]
GWP	Greenhouse effect	Increase in average atmospheric temperature caused by greenhouse gas emissions	[KgCO2 eq]
ODP	Ozone hole Stratospheric ozone depletion	Increase in average atmospheric temperature caused by greenhouse gas emissions	[KgCFC11 eq]
EP	Eutrophication	Lowering of oxygen content in soils and surface waters	[Kg PO_4^{3-}eq]
AP	Acidification	Lowering the pH of lakes, rivers, forests and soils	[KgSO_2 eq]
POCP	Formation of photochemical smog	Pollution due to the presence of unburnt hydrocarbons and nitrogen oxides	[KgC_2H_4 eq]

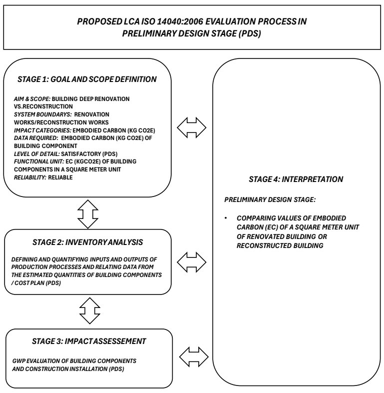

Figure 1. Proposed ISO 14040:2016 estimation process in PDS

3.2. LCA for building construction applications, aim and goal of the research work

Life Cycle Assessment of a building involves many complex calculations [30], therefore specific software are needed. LCA analysis relays on Life Cycle Inventory (LCI) data, and most software tools can rely on a LCI database. There are many tools available for building LCA, as Gabi/Sphera, SimaPro, OneClick LCA, Ecochain and Open LCA. The evaluation of these tools is beyond the scope of the research work undertaken, and the LCA analysis that will follow has benefited from OneClick LCA. OneClick offers many functionalities for the construction sectors, as it can evaluate the environmental impact of construction projects and buildings and can be used related to many environmental protocols such as LEED, DGNB and BREEAM. As predetermined databases are used within the software packages, the LCI and LCIA stages are merged and simplified. Surely, the use of different database and software can give different results in the outputs of the LCA estimation. This is because differences in the software and in the related database, such as different characterization factors, different data sources and different production locations, no frequent updating of the datasets, can produce a wide range of results. Lack of transparency and wrong contextualization can also increase the reliability of LCA results. Pertinent literature has demonstrated the limits of using these tools, with the substantial exception of climate change impact categories [31] [32].

The aim of the research is to evaluate the environmental impact of a construction project on a specific building typology, at a Preliminary Design Stage level. Two strategic choices are addressed, demolition and reconstruction and structural and energy rehabilitation. Cost planning at a preliminary design level is the base used to understand construction activities to be performed and to produce a parametric environmental evaluation at a preliminary design level. The functional unit that is used to perform the LCA analysis is one square meter of gross floor area, over one year (m2/year). The system boundaries included in the LCA study are only the construction stages, new construction or reconstruction or deep renovation of the structure and of the building envelope (fig. 1). The construction or renovation processes are broken down into process units, including construction materials, components and products needed for project completion. Process units or work packages are considered in a standardized form as to relate to the preliminary cost plan used. The life Cycle Stages, according to standard EN-15978 considered in the pilot study are A1 – raw material supply, A2 transport, A3 Manufacturing (Product stage) and A4 transport to building site and A5 installation into building (Construction stage) [27]. System boundaries and life cycle stages of the pilot study are better described in figure 2.

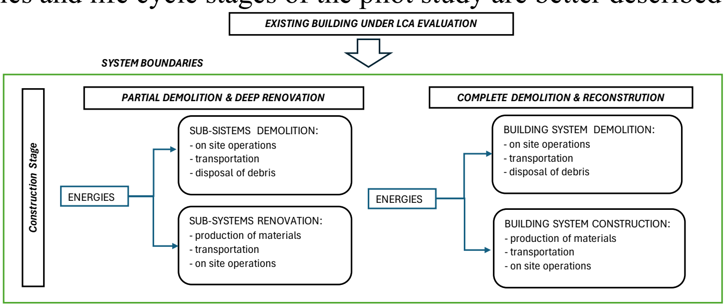

Figure 2. proposed LCA analysis of the alternative building renovation / reconstruction projects

4. Pilot study

The research work under this paper has the aim of detecting a standardize impact of a typical residential building of southern Europe, international style, multi storey building made with a superstructure of reinforced concrete and walls of fired clay bricks.

The proposed approach uses building parametric costs from literature to create a dataset of typical LCA impacts in case of reconstruction or deep renovation. Typical data concerning type and quantity of construction components have been extracted from the Building typology price list of southern Italy [33] by the local Association of Building Contractors. The publication has the aim of evaluating building construction cost at a strategic level, for feasibility studies. Two different types of construction projects have been considered. The first one is a new construction of a residential building for social housing, the second a deep renovation of a similar building addressing energy-based redevelopment (with installation of External Thermal Insulation System ETICS) and structural seismic reinforcement with Carbon Fiber-Reinforcement Polymers (CFRP) stripes. A Work Breakdown Structure has been created and the percentage – based cost plan found in the price list has been used to perform the preliminary LCA analysis for the two alternative strategies, building deep renovation or reconstruction project and evaluate sustainability. The functional unit is one square metre gross internal floor area. The re-construction case was developed first. To simplify the LCA analysis and keeping the estimation on the "safe side", the impact of the complete demolition process of the existing building was not considered. So, in table 2, the percentage of total cost for a new construction of a typical RC multistory building was indicated for each Work Package (WP) of the project, and also the corresponding quantity index (Qi) of construction materials for square metre. The quantity index Qi was found by dividing the Total Estimated Quantity by the Total Gross Floor Area (GFA) of the building. Then, for each WP a category of construction material of the One Click Dataset was selected (tab.2), and the parametric LCA impact was detected (tab.3). The LCA parametric analysis was developed with the software One Click LCA®. The greater impacts, related to the Global Warming Greenhouse Gas Emissions (GHG) for each square metre of functional unit (kg CO2e/m2) were displayed in the following table 3 The same process was performed for a similar building type, but for the case of a deep renovation project. The building renovation aimed at increasing the energy efficiency of the building with an external thermal insulation system installation and at implementing seismic safety by structural reinforcement against earthquake damages (tab. 4 and tab 5). The table 3 and 5 below reports the product (A1 - A3) and construction (A4 - A5) carbon impacts displayed for square metre of Gross Internal Floor Area. Surprisingly, the total parametric impact of Green House Gas Emissions for each functional unit of new construction is 4045 kg CO2e/m2 that is less than the one of deep renovation that is 5217 kg CO2e/m2. This can be because of the high impact of ordinary energy retrofitting with ETICS and structural strengthening with CFRP composites, and the fact that complete demolition of the existing building has not be considered. A limit of the research work is surely the use of only one database of a specific software.

5. Conclusions

The European existing building stock is old, and the need of building renovation is high, as the level of building performance required by new standards and regulations is always increasing, as to address to actual energy efficiency and structural safety requirements. Therefore, real estate operators often face the dilemma of deciding between demolition and reconstruction or deep renovation projects. Many aspects can be considered, but surely building Life Cycle sustainability is one of the most important.

The Life Cycle Assessment LCA has proven to be a reliable tool for the objective assessment of the real sustainability of a building: it makes it possible to highlight the environmental criticalities in the choice of materials by calculating their greenhouse gas emissions and their different contribution to the environmental impact. In this way, it is possible to compare different types of building regeneration processes. As strategic considerations need to be done with preliminary evaluations, a parametric LCA evaluation of building construction renovation projects was proposed, to be performed in the Preliminary Design Stage. First, cost plans of a multistorey residential building type have been analysed, both for new construction and for deep renovation. Then, by performing LCA evaluation, parametric data of GWP indicators have been found. Actually, the output of the analysis depends on the specific data gathered for the pilot study, such as the type of reference buildings, and the used cost analysis database and LCA tool. Addressing the wide range of possible outputs depending on the used tools was not included in this study and it is a limit of the research work. Data found about main typical impact categories of new construction of a RC multistorey residential building are lower than the ones from deep renovation, and this was not expected. Anyway, demolition of the existing building should add a greater amount of impact to the reconstruction strategy, but the possibility of reusing demolished building materials and component needs to be assessed, as can be of importance in the final balance of impacts. In addition to this, the social impact of demolishing an existing building, with the need of moving temporarily the occupants to another building, should be considered. Future research work will address demolition impacts and level of confidence in preliminary LCA evaluation.

Table 2. Typical cost categories of **new construction** of a RC multistorey residential building.

WBS	Work Package	Cost percentage %	Qi (unit/m2GFA)	Categories
NC.01	Construction site (scaff.)	1,73	0,45 m2/m2	Construction/installation
NC.02	Escavations	1,47	1,22 m3/m2	Construction/installation
NC.03	Foundations + superstructure	24,94	0,72 m3/m2 140,99 kg/m2 - 6,26 kg/m2	Ready mix concrete Steel (RC) - Steel structure
NC.04	Cement screed	1,91	1,65 m3/m2	Ready mix concrete lightweight
NC.05	External walls	1,95	32,21 kg/m2	Bricks
NC.06	Curtain walls	12,21	8,29 kg/m2	Steel profiles
NC.07	External walls	1,51	5,70 kg/m2	Bricks
NC.08	Insulations	1,06	1,11 m2/m2	Insulations
NC.09	Roofing	1,33	0,26 m2/m2	Other materials
NC.10	Floorings & tiles	10.87	3,31 m2/m2	Wall & floor tiles
NC.11	Plaster finish	4,61	2,54 m2/m2	Gypsum plaster
NC.12	Paints	2,69	0,81 kg/m2	Paints, coatings and lacquers
NC.13	Doors & windows	13,42	1,93 m2/m2 - 0,12 m2/m2	PVC frame windows - doors
NC.14	Other	20,31	N/A	N/A

Table 3. Main typical impact categories of **new construction** of a RC multistorey residential building.

No.	Result category	Global Warming kg CO2e/m2
1	Ready mix concrete (A1-A3)	2897
2	Steel (A1-A3)	495
3	Bricks (A1-A3)	158
4	Insulation (A1-A3)	32
5	Other mat. (A1-A3)	190
	Sub Total A1-A3	*3772*
6	Transport to the building site (A4)	77
7	Construction / Installation process (A5)	196
	Grand total	**4045**

Table 4. Typical cost categories of **deep renovation** of a RC multistorey residential building.

WBS	Work Package	Cost percentage %	Qi (unit/m2GFA)	Categories
NC.01	Construction site (scaffoldings)	4,21	0,71 m2/m2	Construction/installation process
NC.02	Reinforcement of RC structures	51,75	36,11 kg/m2	Other Materials / Bricks
NC.03	External thermal Insulation	8,02	7,21 kg/m2-0,90 m2/m2	Insulation
NC.05	Doors & Windows	10,70	0,18 m2/m2	PVC frame windows
NC.07	Plaster Finish	2,11	26,74 kg/m2	Gypsum plaster
NC.08	Paints	1,15	0,92 kg/m2	Paints, coatings and lacquers
NC.09	Other	22,06	N/A	N/A

Table 5. Main typical impact categories of **deep renovation** of a RC multistorey residential building

No.	Result category	Global warming kg CO2e/m2
1	Other mat. (A1-A3)	4525
2	Insulation (A1-A3)	38
3	Bricks (A1-A3)	31
	Sub Total A1-A3	4594
4	Transport to the building site (A4)	*81*
5	Construction / Installation process (A5)	542
	Grand total	**5217**

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