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The Circular Economy Model: from the Building Functional Reuse to the Urban System Regeneration

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Indice/Index

A LITERATURE REVIEW ABOUT LIFE CYCLE ASSESSMENT AS A TOOL TO SUPPORT CIRCULAR ECONOMY INNOVATION IN THE BUILT ENVIRONMENT SECTOR

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Abstract

The built environment sector contributes to climate change for different reasons. First of all, to realize a building and for its maintenance, several natural resources and materials are required. There is the necessity of great energy quantities for the realization of a building. The built environment sector is responsible of a good percentage of greenhouse gas emissions, in terms of "operational emissions" and "embodied emission". The aim of this article is to analyse how the circular economy is able to support the buildings sustainable design and what are the evaluation tools to sustain this activity. In this scenario, an analysis of the reference literature about the Life Cycle Assessment was proposed, to understand what are the new research fields in which this tool is tested.

Keywords: circular economy, built environment sector, Life Cycle Assessment

UN'ANALISI DELLA LETTERATURA SUL "LIFE CYCLE ASSESSMENT" COME STRUMENTO PER L'INNOVAZIONE CIRCOLARE NEL SETTORE DELLE COSTRUZIONI

Sommario

Il settore delle costruzioni contribuisce al cambiamento climatico per diversi motivi. Primo fra tutti, per la realizzazione e la manutenzione di un edificio c'è bisogno di una grande quantità di risorse naturali e di materiali. Esiste un grande impiego di energia per la realizzazione di un edificio. Il settore delle costruzioni è responsabile di una buona percentuale di emissioni di gas a effetto serra, in termini di "emissioni operative" e "emissioni incorporate". L'obiettivo di questo articolo è analizzare in che modo l'economia circolare è in grado di supportare la progettazione sostenibile degli edifici e quali sono gli strumenti di valutazione che vengono utilizzati. In questo scenario, è stata proposta un'analisi della letteratura di riferimento sul Life Cycle Assessment, per approfondire in che modo tale metodo di valutazione viene sperimentato e utilizzato nella ricerca scientifica.

Parole chiave: economia circolare, settore delle costruzioni, Life Cycle Assessment

1. Introduction

Climate change is the most serious problem of the 21st century, together with the growth of social inequalities.

In the Sustainable Development Goals (SDGs, Agenda 2030) this topic is widely referred to. Nowadays, there is a necessity to apply all possible strategies to reduce the negative impacts of GHG emissions, that provoke several damages to citizens' health.

A large amount of resources is consumed in cities with negative external effects in terms of pollutants and climate-altering. But, at the same time the cities involved places where the economic, social and cultural factors can be put in symbiosis to manage complexity according to a systemic approach to balance the resources of the territory through sustainable and circular urban strategies (Fusco Girard and Di Palma, 2016).

The "linear economic model" has no future, it is inefficient, it consumes a lot, it makes little, it wastes a lot of environment, it is the bearer of social exclusion, wealth increases and poverty increases for many, unemployment, etc. It is necessary to define a new model of economy.

In this scenario, this paper focuses its attention on the emission of pollutants produced by the built environment sector to understand what are the regenerative strategies to promote a sustainable and circular design both for the new buildings both for the reuse of historic buildings.

Buildings are a major source of greenhouse gases (GHG) emissions and contributors to the climate crisis. The built environment is the cause of most of the material flows in the anthroposphere and the biggest material storage: Over 90% of the anthropogenic stock stored in durable goods can be found in this sector (Schiller *et al.,* 2019).

The "built environment sector" is a major consumer of natural resources. The world's population grows and the resources become scarce and more expensive to access, it is becoming ever more critical to find alternative means of sourcing and using materials (Ellen MacArthur Foundation and Arup, 2018).

The built environment sector has a significant impact on many sectors of the economy, on local jobs and quality of life. It requires vast amounts of resources and accounts for about 50% of all extracted material. The construction sector is responsible for over 35% of the EU's total waste generation (Ellen MacArthur Foundation and Arup, 2018).

The circular economy concepts offer a change to make the step changes needed. It aims to decouple economic growth from resource consumption. Instead, products and assets are designed and built to be more durable, and to be repaired (Ellen MacArthur Foundation and Arup, 2018).

This paper is articulated in different steps:

- The first step is to identify how the built environment sector affect the problem related to climate change. Climate change influences the future development of cities. To clarify this aspect, an overview of the European Commission documents has been made, to understand what are the guidelines to resolve the problems related to climate change for cities, and in particular for the built environment sector;
- The second step is to identify the open research questions about the Life Cycle Assessment to evaluate the buildings circularity. It is important to understand how this method is applied and what are the research sectors in which it is tried out. To make this analysis VOSviewer software was used together with the Web of Science database, with the aim to identify the research categories in which the researchers are testing this

evaluation method;
- In the third step have been analyzed some European certifications that attest the sustainability/circularity of buildings, as Level(s), LEED and GBC Historic building. Three certifications using LCA as a method of evaluation;
- In the fourth step, some conclusion and recommendations are proposed, with the aim to identify what are the open researches questions about the use of LCA.

2. The role of the built environment sector in the climate crisis

The growing urbanization and the depletion of natural resources require the identification of new models to increase urban productivity in the environmental, financial, economic and social dimensions. They require the exploration of new ways of creating “value” while ensuring economic prosperity, valorisation of resources and well-being in a long-term perspective. It is necessary to rethink traditional models by exploring and critically integrating alternative development models.

Over the past seven decades, GDP growth is the primary economic goal of European nations. The growth of different economies, generates different negative environmental impacts. The progressive urbanization of the population has profoundly changed the functioning of the city, creating problems of enormous importance for its governance.

The cities can represent a threat to achieving sustainable development but, at the same time, they can become the starting point to operationalize the principles and objectives of sustainability.

International institutions and agencies (EU, OECD, UN) indicate the cities as privileged places of “public regeneration intervention” to achieve objectives of social cohesion and environmental sustainability, as well as the production of economic resources.

The speed with which cities, and above all, large metropolitan areas, grew, prevented an urban form from being maintained. There has been a loss of a “Forma Urbis” in the expansion areas outside the historic cities, generating urban suburbs without an urban design.

This demographic expansion has generated other relevant problems, such as: traffic congestion, pollution, waste disposal, increased costs, worsening quality of life, increased demand for energy, water and gas. Factors that are leading to the breakdown of the balance between man and the environment.

It is necessary to find a new form of economy able to offer a perspective of economic wealth production based on the (circular) organization of natural ecosystems. The circular economy is directly interdependent with the “regeneration paradigm”, because it tends as much as possible to be regenerative of values, through reuse, recovery, restoration, requalification and recycling. It is an economy with the aim to enhance the citizens quality of life through the creation of new jobs, the creation of livable spaces, the recovery of the memory of the city through the reuse of existing buildings etc., based on the enhancement between the nature and the citizens. It is also possible to say that circularization processes and synergies, which promote resilience and creativity and then sustainability (Fusco Girard, 2010) should be transferred from a sectoral approach (waste management, etc.) to the whole organization of the city, its economy, its social system, its governance (Fusco Girard *et al*., 2014) to improve the urban productivity (Fusco Girard, 2013).

The concept of “circular economy” has its roots in the industrial environment (Rizos *et al*., 2015). The circular economy model can be defined as “restructuring the industrial systems

to support ecosystems through the adoption of methods to maximize the efficient use of resources by recycling and minimizing emissions and waste" (Preston, 2012).
The "circular city" is the regenerative and self-sustainable city that finds its foundation in the territorial / spatial dimension of the circular economy.
It is the city that recovers the value of resources, focusing on the life cycle of materials, recovering all waste as a new resource for future production cycles.
A city is **"**circular" when it thinks back to the enhancement of the environment quality through the rational use of energy, the enhancement of green areas, new water recycling systems and the creation of increasingly qualified employment etc.
It is the city that avoids the waste of all forms of capital: not only of natural capital (soil, areas, etc.), of manufactured capital but also of human/social capital.
The model of the "circular symbiosis city" appears to be the most promising prospect for planning a more desirable city. It is establishing itself as the most concrete answer for outlining future sustainable urban development strategies, capable of responding to the complex challenges of urbanization and urban regeneration.
With the circular economy/city model it is possible to promote greater urban productivity/efficiency by playing on the economies achievable with the synergies, complementarities, and symbiosis of the circuits that close virtuously.
Buildings have a long lifespan of between a few decades to more than 100 years. The replacement rates in Europe for instance suggest that the average lifespan of residential buildings is well above 60 years. Thus, investment decisions on buildings today determine by and large the environmental impacts during several future decades (Frischknecht, 2019).
The Ellen Mac Arthur Foundation with Arup actively participate to define some strategies to apply the principles of circular economy to the built environment sector. Adopting circular economy approaches in a high-growth, high-waste sector like the built environment presents a tremendous opportunity for businesses, governments and cities to minimize structural waste and thus realize greater value from built environment assets (Ellen MacArthur Foundation and Arup, 2018). In a circular economy, renewable materials are used where possible, energy is provided from renewable sources, natural systems are preserved and enhanced, and waste and negative impacts are designed out. Materials, products and components are instead managed in loops, maintaining them at their highest possible intrinsic value (Ellen MacArthur Foundation and Arup, 2018).
The Agenda 2030 for Sustainable Development is an action program for people, the planet, and prosperity signed in September 2015. In this document are defined "The Sustainable Development Goals", 17 Goals with 169 targets to fight poverty, for the elimination of hunger and the fight against climate change, to name just a few (United Nation, 2015). In this document there are different goals referred to the city's development, in particular the goal 12: ensure sustainable consumption and production patterns. In the target 12.2 by 2030, the sustainable management and efficient use of natural resources is required. In the target 12.4 emerges that by 2020, it is necessary an environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks. In the target 12.5 is stressed that by 2030 the substantially reduce waste generation through prevention, reduction, recycling and reuse is required (United Nations, 2015).
In 2017 the European Commission published some documents about the Industrial policy strategy. Among them we remember "State of the Union 2017, Industrial policy strategy:

Investing in a smart, innovative and sustainable industry", a document that define some guidelines for the future development of European industries (European Commission, 2017b).
European industry is already undergoing a significant transformation. The pressure of the natural resources is already leading to a more circular approach to manufacturing. It is necessary to build an industry system greener, more digital and more competitiveness. Industry will need a secure supply of clean and affordable energy and raw materials (European Commission, 2017b).
About the built environment sector, Europe also needs to address the sustainability of construction products and improve the energy efficiency and environmental performance of built assets. A more sustainable built environment will be essential for Europe's transition towards climate-neutrality (European Commission, 2017b).
This approach is supported by new low carbon technologies in the industrial sector, through the use of renewable energy. The new design will follow the circular economy principles towards the ecological transition. This means reducing its carbon and material footprint, reducing production costs. The co-design is supported by Public Private Partnerships, with the aim to attract entrepreneurs, community and activities.
The EU will also support the development of key enabling technologies that are strategically important for Europe's industrial future. These include robotics, quantum technologies, photonics, industrial biotechnology, nanotechnologies, advanced materials (European Commission, 2017b). The recycling and the use of secondary raw materials will help reduce the effects of climate change.
In the European Green Deal of European Commission (11.12.2019) there are some specific criteria to achieve zero climatic impacts by 2050. The aim is to promoting both the efficient use of resources through the circular economy principles, both the restoration of biodiversity and the pollution reduction. So, it is necessary to invest in the technology sector for industries, in the private and public transport, in the decarbonization of the energy sector and a building energy efficiency. Some guide lines have been identified, to build and refurbishment in a sustainable way, giving more attention to the energy sector, promoting the resources adaptive reuse. The buildings are responsible of 40% of the energy consumption. So, it is necessary to promote the energy reconversion of the all buildings (public and private) according to the circular economy principles, reducing the national regulatory barriers (European Commission, 2019b).
In December 2015, the Commission adopted an "Action Plan for Circular Economy" in order to boost employment, growth and investment and develop a carbon-neutral, resource-efficient and competitive economy (European Commission, 2019a).
The Action Plan promoted, for the first time, a systemic approach embracing entire value chains. Through this approach, the Commission has integrated the principles of circularity into plastic production and consumption, water management, food systems and the management of specific waste streams. This plan provides 54 actions.
In 2019, the European Commission came to the almost complete drafting of this document, adopting a comprehensive report on the implementation of the "Circular Economy Action Plan". The report presents the main achievements under the Action Plan and sketches out future challenges to shaping our economy and paving the way towards a climate-neutral, circular economy where pressure on natural and freshwater resources as well as ecosystems is minimized (European Commission, 2019a).

In this document there are some directions for the eco-compatible design. The aim is to define some "guidelines" to develop new laws about the materials efficiency and the future requisites of sustainable design, in terms of durability, reparability and recyclability of products.
The circular economy is the strategy able to plan the entire life cycle of the materials/products, starting from their design, promoting sustainable consumptions, and to use sustainable and renewable resources. In this document are identified different strategic actions as: to promote the use of sustainable products, according to the guidelines of European Commissions, empowering consumers and public buyers, to identify the major sector that used many resources, promote the ICT technologies, to promote the reuse of plastic materials, to invest in the reuse of textile; to invest in the built environment sectors.
The European Commission adopt a common European strategy for the built environment sector, to improve the buildings sustainability. With half of all extracted materials and energy, and one third of the total waste generated, the construction sector represents the greatest stake in the European Union's efforts to make our economy circular (European Commission, 2017a). The Paris Agreement demands the building and construction sector to decarbonize globally by 2050, if we wish to avoid the catastrophic impacts of a +2 degree rise in temperature (European Commission, 2017a).
In this document, about the problem related to the built environment sector, the European Commission promote circularity principles throughout the lifecycle of buildings by:

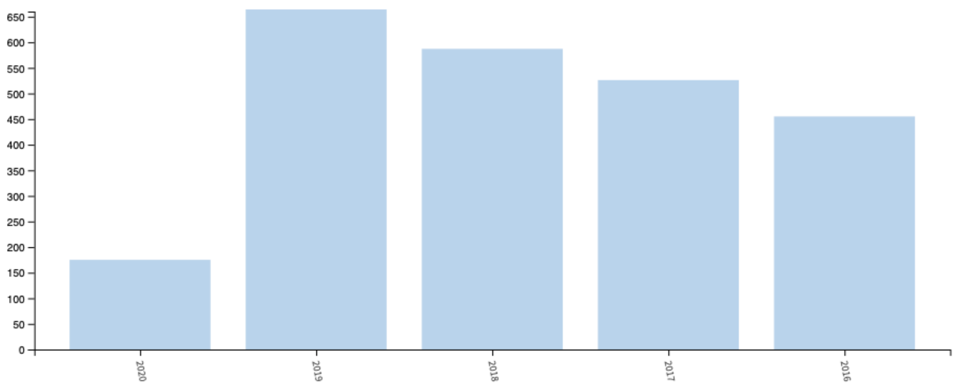
- addressing the sustainability performance of construction products in the context of the revision of the Construction Product Regulation, including the possible introduction of recycled content requirements for certain construction products, taking into account their safety and functionality;
- promoting measures to improve the durability and adaptability of built assets in line with the circular economy principles for buildings design36 and developing digital logbooks for buildings;
- using Level(s) 37 to integrate life cycle assessment in public procurement and the EU sustainable finance framework and exploring the appropriateness of setting of carbon reduction targets and the potential of carbon storage;
- considering a revision of material recovery targets set in EU legislation for construction and demolition waste and its material-specific fractions;
- promoting initiatives to reduce soil sealing, rehabilitate abandoned or contaminated brownfields and increase the safe, sustainable and circular use of excavated soils (European Commission, 2017a).

3. Materials and methods: the analysis of the scientific literature about Life Cycle Assessment to support the new buildings circular projects

The Life Cycle Assessment is considered an evaluation tool capable to be used to supporting the sustainable building project, especially to evaluate the energy efficiency aspect, the embodied energy calculation, the evaluation of the new innovative/technological materials.
In this step, the analysis of the scientific literature was made through the use of a specific software called VOSviewer. It is a tool for creating maps based on network data and for visualizing and exploring of the same.
The construction of a "data network" is created through the research works collected in the "Web of Science, Scopus, Dimensions, and PubMed database. This type of analysis helps

the researchers to understand what is the scientific landscape about the interested research thematic. The keywords present in the VOSviewer map highlight the research sectors in which the scientific community are investigating.
After the analysis of the scientific landscape, the second step has been to select all the relevant study about the Life Cycle Assessment for buildings, to understand what are the new technologies/protocols to design and evaluate both the circularity of a new building project both of the historic building's refurbishment/reuse project.
For the selection of the scientific paper present within of the Web of Science collection have been used these key words: LCA for buildings. Then some search filters were also inserted: the first is the paper published by 2014 to 2019, the second is only about the scientific papers, and the third only English papers.
The Web of Science systems, with this indication, has selected more than 2,387 records for all fields of the Life Cycle Assessment. These records have been assembled into different topic: 757 in environmental sciences; 662 in engineering environmental; 614 in construction building technology, 543 in energy fuels; 749 in green sustainable science technology, 638 in engineering civil; 193 in environmental studies; 89 in materials science multidisciplinary and 62 in thermo solutions (Web of Science elaboration). About this analysis, another interesting aspect is the classification of the research papers for the year of the publication, we have chosen the last five years. It is an important data to understand how the interest of the scientific community grow in this research field (Fig. 1).

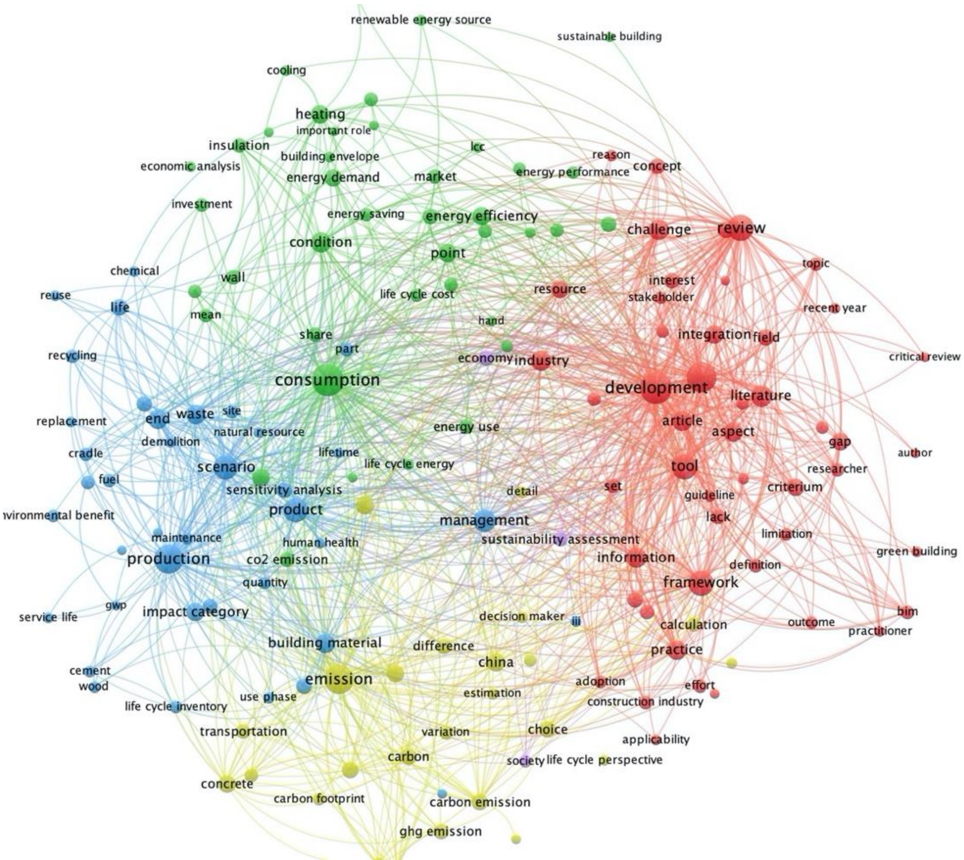
Fig. 1 – Classification of research paper per year (last five years)



Source: Web of Science elaboration

Through this analysis, it is possible to understand also what are the organizations that enhanced this research field. Probably, the ETH Zurich University, the Polytechnic University of Milan, the Technical University of Denmark are the Universities that carries out a deep research concerning the "Life Cycle Assessment" for buildings.
All this data has been included in the VOSviewer software to elaborate the scientific landscape map (Fig. 2).

Fig. 2 – The cluster sector in which LCA was applied



Source: map elaborated from web of science data and VOSviewer

The software elaborates all the data coming from Web of Science and identify all the research relevant questions, identified in the form of “Key words”. The dimension of the circle identifies the weight of the relevant questions and the circle colours identify the cluster sector (categories) in which the researchers promote their studies.

In this “map visualization” there are five clusters with 157 items. For each item have been chosen the most relevant, able to support the circular building design in the context of future development of the circular cities (Table 1).

The distance between to items in the visualization, identify the relationships in terms of citations in the scientific literature.

Table 1 – The five cluster and the items

Red cluster: Development (49 items) Selected items	**Green cluster: Consuption** (41 items) Selected items	**Blu cluster: Production** (39 items) Selected items	**Yellow cluster: Emission** (25 items)	**Violet cluster: Sustainability assessment** (3 items)
- Development - Integration - Building Information model - Green Building - Guide line - Construction industry - Resource - Building Life Cycle - Tool - Stakeholders - Decision making - Future research - Critical review - Challenge - Applicability	- Co2 emissions - Construction sector - Consumption - Economic analysis - Economic performance - Energy demand - Energy efficiency - Energy saving - Energy saving - Heating - Life cycle analysis - Life cycle cost - Life cycle energy - Renewable energy source - Sustainability building	- Building material - Demolition - Environmental benefits - Global worming potential - Human health - Impact category - Life cycle inventory - Maintenance - Management - Natural resources - Recycling - Replacement - Reuse - Sensitivity analysis - Waste	- Carbon - Carbon emission - Carbon footprint - Choice - Construction material - Decision maker - Ghe Emission - Greenhouses gas emission - Life cycle perspective - Residential building - Transportation	- Economy - Society - Sustainability assessment

Source: VOSviewer elaboration

4. Analysis of scientific literature review results about LCA

After a first analysis of the literature review, it is clear the LCA is the assessment tool that nowadays support all the processes/protocols able to certificate the buildings sustainability and circularity.

The Life Cycle Analysis was originally engaged as a descriptive model of the analysis of the production of consumer goods and as a tool for the analysis of business strategies. The life cycle of a product is defined as the period of time from its introduction into the market until its disappearance from it (De Cristofaro and Konig, 2015).

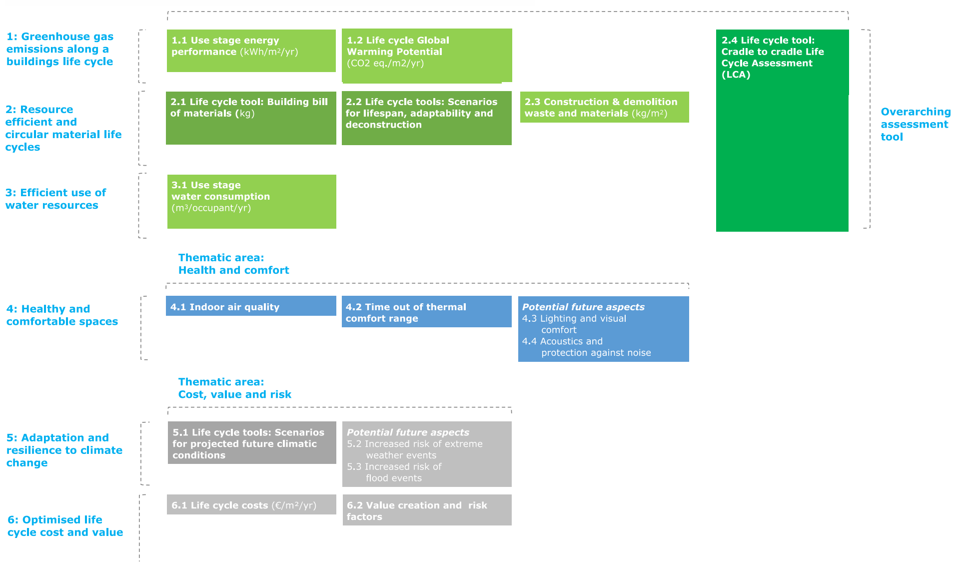
The application of the sustainable development principles in construction involves the adoption of economic, energy and ecological criteria for the evaluation of the project. This complex task of processing and evaluating a whole range of information, extended to the entire life cycle of a building, is generally only manageable through integrated design and evaluation systems (De Cristofaro and Konig, 2015).

All the “green buildings certifications” follow the EN 15978 “Sustainability of construction works, Assessment of environmental performance of buildings. Calculation method” of 2011 and the EN 15804 “Sustainability of construction works, Environmental product declarations. Core rules for the product category of construction products” of 2012 (European Committee for Standardization, 2011; 2012).
An assessment tool able to evaluate the building projects circularity through the reduction of the greenhouses gas emissions is Level(s). Its experimentation has been promoted by the European Commission in 2017.
This evaluation method considers six ‘criteria’ to evaluate the environmental impact (through the whole building life cycle):

1. Greenhouse gas emissions along a building’s life cycle;
2. Resource efficient and circular material life cycles;
3. Efficient use of water resources;
4. Healthy and comfortable spaces;
5. Adaptation and resilience to climate change:
6. Optimized life cycle cost and value (European Commission, 2017a).

There are 14 indicators, divided for the six criteria, able to measure the project circularity, clarified in the figure 3 (Fig. 3).

Fig. 3 – The Level(s) indicators



Source: European Commission, 2017

The primary objective of Level(s) is to help construction and real estate stakeholders to reduce the environmental impacts of the buildings they invest in, design, build and occupy, by providing them with a reporting framework that links the building's individual performance with European policy objectives (European Commission, 2017a). The LCA is the evaluation tool that support Level(s). Also, the LEED certification (Leadership in Energy and Environmental Design) are accomplished through support of LCA method. It is the most widely used green building rating system in the world. Available for virtually all building types, LEED provides a framework for healthy, highly efficient, and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement and leadership (Green Building Council Italia, 2016). The LEED certification demonstrate the building sustainability. They are performed on every type of building with different protocols for: new buildings, new interiors, existing building, small houses, neighborhood development, cities and communities, residential, recertification and retail. LEED certification is divided in BD+C for building design and construction (also includes applications for schools, retail, hospitality, data centers, warehouses and distribution centers and healthcare), ID+C for Interior Design and Construction (also includes applications for retail and hospitality), O+M Building Operations and Maintenance (also includes applications for schools, retail, hospitality, data Centers, and warehouses and distribution centers) (Green building Council USA).
The criteria that characterize the LEED certification are:

- Integrative processes (integrated planning and design);
- Location and transportation;
- Sustainable site;
- Water efficiency;
- Energy and atmosphere;
- Materials and resources;
- Indoor environmental quality;
- Innovation;
- Regional priority (Green building Council USA).

Each criterion has specific through some sub-criteria (e.g.: Table 2 – Sub-criteria for LEED certification).

Table 2 – Sub-criteria for LEED certification

Criteria	Sub-criteria
Integrative processes	Protection of sensitive areas Surrounding densities site diversification Accessibility to transport services Cycling infrastructure Reducing the size of car parks Green vehicles
Location and transportation	Environmental analysis of the site Site evaluation Site development, habitat protection and Restoration Open spaces

	Rainwater management Heat island reduction Light pollution reduction Site master plan Tenant design and construction guidelines Place of respite Direct exterior access Joint use of facilities
Water efficiency	Outdoor water use reduction Indoor water use reduction Building-level water metering Outdoor water use reduction Indoor water use reduction Cooling tower water use Water metering
Energy and atmosphere	Fundamental commissioning and verification Minimum energy performance Building-level energy metering Fundamental refrigerant management Enhanced commissioning Optimize energy performance Advanced energy metering
Materials and resources	Storage and collection of recyclables Construction and demolition waste Management planning Pbt source reduction – mercury Building life-cycle impact reduction Building product disclosure and optimization – environmental product declarations Building product disclosure and optimization – Sourcing of raw materials Building product disclosure and optimization – material ingredients
Indoor environmental quality	Minimum indoor air quality performance Environmental tobacco smoke control Minimum acoustic performance Enhanced indoor air quality strategies Low-emitting materials Construction indoor air quality management Plan Indoor air quality assessment Thermal comfort Interior lighting Daylight Quality views Acoustic performance
Innovation	Innovation LEED accredited professional
Regional priority	Regional priority

Source: elaboration by Green Building Council USA

Another interesting certification is "GBC Historic Building", that always uses LCA as evaluation tool.
In this case, to certificate the sustainability of an historic building it means regenerating it, because probably it has lost its characterization, that is the "complex of its essential and distinctive characters (Bianchi, 2019). The "Toledo Declaration" (2010) indicates the strategic importance of the "integrated urban regeneration". To realize this concept, it is necessary "a shared urban alliance by all the involved stakeholders in the city- building process, based on the consent and legitimated by new governance forms" (Bianchi, 2019).
There are a lot of case studies about the reuse of building complexes, as churches, villas, hospitals, archaeological industrial buildings, monasteries, and many others. Some of this have been converted in residential buildings, realized in the 1960-1970 to respond to the demand for housing by population groups with very low-income levels. The neighbourhoods characterized by the presence of abandoned buildings, represents the "open wound of urban cities" (Bianchi, 2019).
There are a lot of good practice that confirmed the success of urban regeneration projects about the abandoned city areas, as Bilbao, La Ruhr, Glasgow, Lipsia, Rotterdam, Amsterdam, Liverpool, Barcelona and some others.
Nowadays, it is important to considered the role of the new technologies for the reuse of the historic buildings. The most important aspects that must be considered are the building energy efficiency and the use of innovative and sustainable materials.
Improving energy efficiency will lower carbon emissions and fuel bills and often increase comfort. More broadly, improving energy efficiency forms a part of the wider objective to achieve a sustainable environment. It is a widely held view that older buildings are not energy-efficient, and must be radically upgraded in order to improve their performance (Historic England, 2018).
On these theoretical bases are based the "GBC Historic building", that's certificate the sustainability/circularity of an historic buildings. This protocol was experimented by Green Building Council, in 2012. The reference protocol is LEED 2009 "Italy's new buildings and refurbishment" (Green Building Council Italia, 2016). The guide line of GBC certifications support the reuse project about the interventions on the air conditioning systems, on the reorganization of internal functional spaces, on the facades, on insulation systems etc.
The GBC Historic Building verification system measures the sustainability of the building according to the thematic areas (criteria) that characterize the LEED/GBC rating system, adding one, specific to the conservation area, as shown below:

- Historic values,
- Site sustainability;
- Water management;
- Atmosphere and energy;
- Materials and resources,
- Internal environmental quality;
- Innovation in design and regional priority (Green Building Council Italia, 2016).

Each criterion has specific through some specific sub-criteria (Table 3).
To identify the "historic value" there are some others criteria to investigate: preliminary cognitive investigations, advanced cognitive surveys (energy surveys), advanced cognitive surveys (diagnostic investigations on materials and forms of degradation), advanced

cognitive surveys (diagnostic investigations on structures and structural monitoring), reversibility of conservative intervention, compatibility of intended use and settlement benefits, chemical-physical compatibility of mortars for the restoration, structural compatibility with existing structure, sustainable restoration site, scheduled maintenance plan and specialist in architectural and landscape heritage (Green Building Council Italia, 2016).

Table 3 – Sub-criteria GBC Historic building certification

Criteria	Sub-criteria
Historic Values	The preliminary cognitive phase The project phases The construction site phase
Site sustainability	Sustainable management of the yard Recovery of green areas and degraded sites Alternative transport Rainwater runoff management Heat Island effect Reduction of light pollution
Water management	Reduction in the use of drinking water Monitoring and accounting for volumes of water consumed
Atmosphere and energy	Improvement and control in operation of energy performance Coolant management Use of energy produced from renewable sources
Materials and resources	Waste reduction and management Re-use of buildings Reuse of materials Selection of sustainable material
Internal environmental quality	Improve indoor air quality Check internal sources of contamination Use materials that are not harmful Allow occupants to control their comfort conditions
Innovation in design and regional priority	Regional priority

Source: elaboration by Green Building Council Italia

4.1 The "GBC Historic building" case studies

There are just some good practices, which can be taken as a reference about GBC as the Guinelli building in Ferrara and the *Scuderie di Sant'Apollinare* in Perugia (Italy) (Green Building Council Italia, 2016).

The seismic damage repair that devasted Emilia in 2012, was the reason for a sustainable seismic improvement and regeneration of *Palazzo Gulinelli*, whose origins date back to the late fourteenth century, is an important historic building of 3,850 square meters on 3 floors, surrounded by an historic garden of about 10,000 square meters (Green Building Council Italia, 2016).

The aim of the restoration project is to re-functionalizing the building in a sustainable way,

through: the use of ecological and second-generation materials, the use of dry technology and the reuse of materials from the historical site (considering the building as a quarry). This type of intervention has led to the application of the GBC Historic Building protocol.
The eco-sustainable project also included the introduction of an Xlam glulam structure in the building, covered by a green walkable terrace. The roof was completely disassembled and restored, with the inclusion of an insulating layer. All the insulating materials are natural, of recycled origin and with recyclable properties (Fig. 4).

Fig. 4 - Guinelli building in Ferrara

Source: Green Building Council, 2016

The energy requalification project was carried out with the insertion of an internal coat along the walls of all the floors. The plant engineering project started with the idea of respecting the place and exploiting the peculiarities of the building and its original ventilation ducts (one of the very few cases of historical air conditioning system in Italy). A heating/cooling system with radiant underfloor heating and cooling panels, laid dry and / or nailed to the floor, has been inserted (Green Building Council Italia, 2016). All the damaged lintels have been restored, favouring conservative or slightly invasive techniques, respecting the historical architectural value of the building. The project was realized with BIM (Building Information model), able to activate a collaborative/integrated design for the structural and architectural intervention. The Sant' Apollinare building in Perugia was a Benedictine Monastery. The restoration project has been made for a seismic adjustment and energy requalification.
The building is completely self-sufficient thanks to a trigeneration plant fed by biomass (vegetable oil from the thistle, oleaginous biomass from the surrounding countryside) and biogas coming from the building's wet waste, which produces heat, cold and electricity. The building's manholes are connected to a rainwater collection tank, which is used for flushing toilets (Green Building Council Italia, 2016).
Different materials with a low environmental impact and of local origin were used:

- The old roofing tiles have been partially recovered. The new tiles are photocatalytic to reduce pollution;
- The paving is made of local gravel selected on the basis of the type of stone and its

grain size (4/6 mm) so as to be high permeable;
- The outer coat (10 cm) is made of locally sourced recycled cork and completely removable as requested by the Superintendence (Fig. 5).

Fig. 5 – Sant'Appollinare in Perugia

Source: Green Building Council, 2016

4.2 The use of LCA and MLCA

Another interesting perspective about the use of LCA is perspective of professor Guillame Habert (ETH Zurich). In a very recent study (2019), he affirms that LCA can be used not only as an ex-post evaluation, but also as an ex-ante evaluation. The LCA ex-ante is very relevant to the realization and the promotion of the innovative materials for architecture, where there isn't any data to extract by a consolidate database (Hollberg *et al.*, 2019). In this perspective, the LCA can be accompanied by multi criteria evaluation processes (MLCA), because there are different actors that participate to the design/reuse of a building. He called this methodologies a-LCA "anticipatory LCA" (ex-ante), able to evaluate both the stakeholder's different needs that participate to the building design, both the efficiency of the new materials proposed for its realization (Garrido *et al.*, 2017). New technical solutions are being developed to address the drawbacks of traditional construction methods. Alternative materials are under scrutiny, for example, insulation cork boards (Silvestre *et al.*, 2016) and thermal mortars with nanomaterials (Garrido *et al.*, 2017).
The developers and manufacturers of construction materials can learn from efforts in the field of emerging technologies. Even though a-LCA was developed for high technology markets, its basic principle distinguishing it from ex post LCA is simple: an interdisciplinary collaboration is required to integrate social, environmental, and technical aspects and to steer sustainable technology development (Wender, *et al.*, 2014). The a-LCA can be used for photovoltaic (PV) technologies. LCA is usually conducted to evaluate and compare environmental performance of products. Results in form of characterized scores can be compared within each impact category but not across categories, leaving the target audience with no direct recommendation for the decision-making process (Myllyviita *et al.*, 2014).
Zanghelini, Cherubini and Soares (2018) stated that MCDA is specifically useful to integrate social, economic, and environmental aspects. Other factors usually included in MCDA are cost, comfort, structural, and thermal performance, with varying focus on different indicators, service life, or appropriateness for local context (Chantrelle *et al.*,

2011). Different stakeholder groups will put different emphasis on those factors (Linkov and Seager, 2011). Stakeholder group-specific weight sets or value functions (Parnell, 2016) can be used to evaluate the trade- offs between the criteria. In construction, a typical multidimensional trade-off problem is time–cost–quality.

5. Conclusions

In our increasingly urbanized world, cities face important challenges (related to the economic, social and environmental crisis), related to three major changes: demographic / social changes (population growth, social fragmentation etc.), structural changes (economic globalization) and environmental changes (climate change and pollution).

The "linear economy" is a system that must be overcome. Circular economy is a "systems-approach", that helps to spot opportunities for 'closing the loops' in biological cycles (restoring non-toxic materials into the biosphere while rebuilding natural capital) and technical cycles (reducing the dependence on virgin materials by restoring products, components and materials into the market at the highest quality possible and for as long as possible (Ellen MacArthur Foundation, 2015).

The circular economy (CE) is an inspirational strategy for creating value for the economy, society and business while minimizing resource use and environmental impacts trough reducing, re-using and recycling.

The aim of this research is to identify what is the role of the evaluation tools able to support the circular buildings design, also in terms of the reuse and refurbishment.

The analysis conducted in this paper demonstrates that the LCA is an evaluation tool able to evaluate the entire building life cycle, considering the sustainability/circularity of the construction materials.

There are interesting research field about this topic, especially referred to the use of LCA to monitor the new building materials. There is an increased interest in the sustainability assessment of building materials and for standardization in construction (Xie *et al*., 2016). Furthermore, "construction 4.0" and digital fabrication are revolutionizing the construction industry (García de Soto *et al.*, 2018) by increasing speed and decreasing workmanship.

The LCA evaluation is a complex tool (in terms of data, details which are require etcetera). Some new simplified versions are going to be proposed also for the reuse of existing buildings. This could allow a more rapid assessment. But it is not still clear if they are really useful in operational terms.

Another consideration is about the need to integrate the LCA assessment process with others evaluation tools. Also, if we assume that the battle of climate change is our first end prior goal, we have to consider not only greenhouses emissions/ impacts but all the other form of pollution together with financial/economic costs and benefits (employment etcetera). The embodied CO2 cannot become the unique indicators for improving choices.

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