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Circular Economy Strategies in the Historic Built Environment: Cultural Heritage Adaptive Reuse

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Abstract

Circular Economy (CE) is currently promoted through policy, urban and regional strategies as well as emerging as a relevant research sector. Within this context, circularity in the built environment is attracting attention with applications in many design and urban projects. The general principles of CE are applied to existing and new buildings, focusing on the “end-of-life” stage and developing sustainable innovative solutions to optimize dismantling and reuse of materials and technological parts of buildings. However, in historic urban areas the principles of dismantling and reuse of materials remain barely applicable (end-of-life), as well as the application of standard renewable energy systems (usage), due to cultural heritage unique characteristics and heritage regulations oriented to its preservation, conservation and transmission to future generations. As a consequence, adaptive reuse of cultural heritage seems to be the one of the most viable solution to apply CE in the historic built environment. In this article, we aim to identify CE solutions and to lay the foundation for the future development of a system of indicators able to support circular adaptive reuse choices in the historic built environment. The starting point is the Horizon 2020 “CLIC” project (Circular models Leveraging Investments in Cultural heritage adaptive reuse), which focuses on adaptive reuse as a key strategy for CE implementation in historic cities and regions. The concepts of Circular Economy, Circular Built Environment and Circular Urban Metabolism are explored. Under these perspectives, three representative case studies are described: the first is “De Ceuvel” project in Amsterdam, a second application at a different scale is referred to “Rehafutur Engineer’s House project” (France), and finally, the circular adaptive reuse of a rural village in Spain, within the “ReDock project” in the Altiplano region in Spain, is explored. Conclusions highlight the need of suitable indicators synthesizing theory and practice of CE in historic built environment, starting from the recognition of multiple impacts of cultural heritage adaptive reuse practices.

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1 Introduction

As a concept with the potential to guide the transition towards more sustainable cities, Circular Economy (CE) is currently promoted through policy, urban and regional strategies as well as emerging as a relevant research sector (Marin & de Meulder, 2018). Within this context, circularity in the built environment is attracting attention with applications in many design and urban projects. This is the case because increased circularity in the built environment offers many benefits such as economic growth, reduced environmental impact and improved quality of life (EMF et al., 2015). The general principles of CE are applied to existing and new buildings, focusing on the “end-of-life” stage and developing sustainable innovative solutions to optimize dismantling and reuse of materials and technological parts of buildings.

Ellen MacArthur Foundations (EMF et al., 2015) defines four domains in which CE can be applied in the built environment, namely: “construction”, acknowledging that 10-15% of building material is wasted during the construction phase; “utilization”, avoiding empty and abandoned spaces; “usage”, in terms of energy consumption; and “end-of-life”, avoiding landfill.

However, in historic urban areas the principles of dismantling and reuse of materials remain barely applicable (end-of-life), as well as application of standard renewable energy systems (usage), due to cultural heritage unique characteristics and heritage regulations oriented to its preservation, conservation and transmission to future generations.

Cultural heritage is ideally projected to an indefinite time horizon, towards eternity. It represents the memory and identity of urban/territorial systems (Fusco Girard, 2018). In the case of cultural heritage, CE models can only be oriented to the conservation of its functionality and “use values” over time, or to the adaptation of the cultural asset to new functional needs, identifying new uses compatible with the conservation of authenticity and integrity as well as the contemporary needs, to the durability and reuse of abandoned areas/buildings and to the preservation of their “embodied energy”. For these reasons, it is possible to state that there are two main alternatives for the application of CE in the historic built environment, the first is the adoption of a conservative perspective towards historic urban areas/buildings and the second is the adaptive reuse of cultural heritage. The latter «is a restorative, regenerative and a sustainable form of conservation that

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extends the life of our cherished heritage, stimulate civic pride and responsibility, and preserve cultural values for future generations» (Gravagnuolo et al., 2017, p. 186).

Yet, research on the application of CE principles in the built environment has mostly concentrated on construction waste minimisation and recycling (Tebbatt Adams et al., 2017). In this article, we aim to identify CE solutions and to lay the foundation for the future development of a system of indicators able to support circular adaptive reuse choices in the historic built environment. The main reference is represented by the Horizon 2020 “CLIC” project (Circular models Leveraging Investments in Cultural heritage adaptive reuse), that acts as a general framework, focusing on adaptive reuse as a key strategy for CE implementation in historic cities and regions. This is a relevant area of enquiry since the application of circular principles to the historic urban landscape «leads to the ability of maximizing the value of settlements, activating social, economic and environmental synergies» (De Medici et al., 2018, p. 3).

The paper is organized as follows: the first part presents a description of the concept of CE applied to the built environment and the concept of Urban Metabolism (UM), while the second part is focused on the way to assess circularity with reference to the historic built environment, defining a specific methodology.

The third part, presents an analysis of three representative case studies linked to the concept of CE in the historic built environment and to some extent also to circular UM. The first case is represented by “De Ceuvel” project in Amsterdam, focused on the reuse of old boats to create a full “circular” neighbourhood, in terms of materials, energy and even financial resources. A second application at a different scale is referred to “Rehafutur Engineer’s House project” in France, an adaptive reuse of a historic villa following CE principles, more focused on building materials. Finally, the adaptive reuse of a rural village in Spain, within the “ReDock project” in La Junquera, will be explored highlighting circular metabolisms of materials, energy and financial resources.

These projects will be analysed to lay the foundation for the future definition of “key performance indicators” that could be used to foster and to monitor the implementation of CE strategies in the adaptive reuse of cultural heritage.

In the last part of the paper, some main conclusions are presented, together with some identified limitations and suggestions for future applications.

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1.1 Circular Economy, Circular Built Environment and Circular Urban Metabolism

"CE is currently high on the agenda of business leaders, policy makers and academic researchers. Conceptualised as «an industrial system that is restorative or regenerative by intention and design" (EMF & McKinsey, 2012, p.7), CE appears to be a promising vision for inspiring change towards a more prosperous as well as more environmentally and socially sustainable economy. Notably, it is seen as an effective instrument to deal with the rising environmental, social and economic concerns of this particular historical junction. Several practitioners' studies and scholars argue that in a circular scenario, supply and resource price volatility as well as natural resources depletion could be mitigated, and that employment and innovation opportunities will emerge (EMF & McKinsey, 2012; Jones & Comfort, 2017; Kalmikova et al., 2017; Ilic et al., 2018).

As a consequence, several stakeholders (e.g., industries, governments, cities, supranational bodies, non-governmental organisations) are involved in numerous initiatives to promote the implementation of CE principles. The predicted rise in population to 8.6 billion in 2030 (United Nations, 2017) will inevitably translate in greater rates of urbanisation with the resultant increase in infrastructure investments (EMF, 2017). This is worrying because cities already account for 60-80% of greenhouse gas emissions, 75% of natural resource consumption and 50% of global waste production (ibid.). For these reasons, the involvement of cities for a truly transition towards CE is necessary. Cities with their unique concentration of resources are well positioned to lead on the global transition to CE (ibid.). Not surprisingly then, circularity in cities is currently promoted through policy, urban and regional strategies as well as emerging as a relevant research sector (Marin & de Meulder, 2018). According to the Ellen MacArthur Foundation (2017, p. 7),

> "a circular city embeds the principles of a CE across all its functions, establishing an urban system that is regenerative, accessible and abundant by design. These cities aim to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology. A circular city seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens, while aiming to decouple the creation of value from the consumption of finite resources".

DOI: 10.3217/978-3-85125-668-0-08

One of the constitutive elements of a circular city is a circular built environment, which is

> "designed in a modular and flexible manner, sourcing healthy materials that improve the life quality of the residents, and minimise virgin material use. It will be built using efficient construction techniques, and will be highly utilised thanks to shared, flexible and modular office spaces and housing. Components of buildings will be maintained and renewed when needed, while buildings will be used where possible to generate, rather than consume, power and food by facilitating closed loops of water, nutrients, materials, and energy, to mimic natural cycles" (EMF, 2017, p. 7).

Circularity in the built environment is attracting attention with applications in many design and urban projects. This is the case because it offers many benefits such as economic growth, reduced environmental impact and improved quality of life (EMF et al., 2015). However, research on the application of CE principles in the built environment is just emerging and it has mostly concentrated on construction waste minimisation and recycling (Tebbatt Adams et al., 2017) despite the fact that there are several other circular strategies, i.e., retain, refit, refurbish, reclaim, reuse and remanufacturing (Cheshire, 2016), which offer more significant comprehensive sustainability benefits.

Furthermore, the adaptive reuse of Cultural Heritage allows reducing the metabolic flows crossing single buildings as well as the whole city. These flows are represented by the raw material in input, thanks to the use of already existing resources and at the same time by the output flows coming from the construction of new built heritage (especially Construction and Demolition Waste), together with the use of sustainable and compatible technologies that enable to improve the environmental performances of the use phase.

Therefore, each city with all its components can be considered as a living organism crossed by flows of energy and resources allowing its functioning, and for this reason it has its own metabolism. The concept of UM (Fig. 14) in general is a scientific phenomenon based on the principles of conservation of mass and energy, that has been defined as "the sum of the technical and socio economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy *et al.,* 2007, p.44).

DOI: 10.3217/978-3-85125-668-0-08

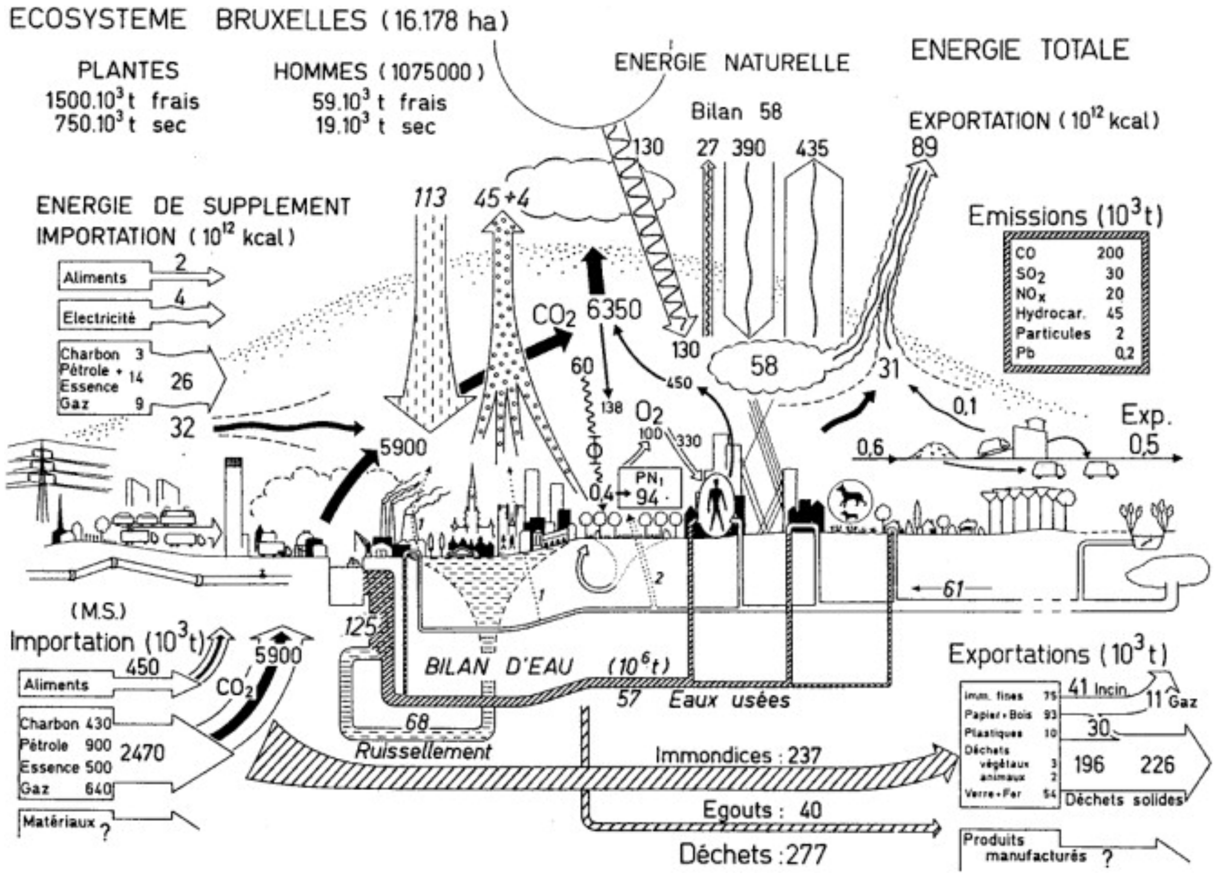

Fig. 14: *The urban metabolism of Brussels (source: Duvignead and Denayeyer-De Smeet, 1977)*

Taking into account the flows of energy, water, nutrients and waste that circulate within a city allows understanding the impacts deriving from the urban development and from the human, social and environmental activities (Mostafavi *et al.,* 2014), making it possible to perform a multidimensional and multi-scale sustainability assessment (Beloin-Saint-Pierre *et al.,* 2017). UM assumes as a fundamental prerogative that cities can be assimilated to living organisms and in order to guarantee the functioning of the various activities at different scales, they need input flows of matter and energy while generating output flows in the form of waste and emissions. Urban Metabolism in cities is actually characterized by a linear development model, where the output flows are not properly reintroduced into the system, differently from what happens in natural systems, characterized by a circular metabolism model.

The concept of circular UM can be found, at different scales and from different points of view, in some of the case studies analysed in the present paper, demonstrating that the adaptive reuse of cultural heritage can contribute to the loop closure.

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In addition, there are different UM evaluation methods and an example is that of Metabolic Impact Assessment (Pinho et al., 2013) that enables the assessment of a certain transformation on the urban metabolism performance of an urban system.

2 Materials and Methods: Assessment of circularity for the historic built environment

This study aims to lay the ground for the identification of possible circularity indicators for the Historic Built Environment that can be employed in a broader Urban Metabolism (UM) perspective to analyse flows of materials, energy, water, waste, as well as financial resources and socio-cultural aspects, assessing to which extent cultural heritage adaptive reuse can contribute to 'closed' urban metabolisms in a CE perspective.

A hybrid deductive and inductive methodology is applied, starting from theoretical aspects of the CE and circular city models, identifying how cultural heritage contributes to CE implementation, and then analysing three practical adaptive reuse case studies which apply circular economy principles in different ways and at different scales to identify circularity indicators.

According to several studies on CE (Ghisellini et al., 2016, Homrich et al., 2017, Kirkhherr et al., 2018), different frameworks can be adopted to synthesize CE principles: the "9Rs" (Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover), the "ReSOLVE" framework proposed by Ellen MacArthur Foundation (EMF *et al.,* 2015), are two of the most commonly applied. Moreover, specific studies on cultural heritage adaptive reuse in the context of the CE (Gravagnuolo *et al.,* 2017) argue that heritage reuse contributes in many ways to CE: preventing the use of raw materials, reducing construction waste and landfill, promoting a 'second life' for abandoned heritage assets, also through repairing, maintenance and refurbishment, creating new products from different technological parts of buildings, repurposing buildings through new functional uses, recycling materials wherever possible.

However, CE aspects related to materials, energy, water and waste do not represent a comprehensive approach to CE, considering particularly the 'urban functions' not only related to the availability of materials/goods, water, energy and food, but also to different 'soft' functions related to cultural diversity, identity, relationships, access to financial resources, access to services, etc. Definitely, ultural heritage adaptive reuse can

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contribute to maintain and enhance urban functions in a circular perspective through three main levels[1]:

• **cultural values conservation/regeneration** (extending the life-time of heritage assets in a circular perspective, including the rights of future generations to benefit of cultural capital);

• **circularity of conservation interventions** (adopting circular building construction strategies such as reusing and recycling of materials, recovering of ancient water management systems, adoption of efficient energy systems and renewable energy sources, nature-based solutions, zero-waste management systems, etc.);

• **circularity of outcomes coming from reuse initiatives** (economic, social, environmental and cultural impacts directly or indirectly linked to the new functions of buildings and sites, including jobs creation, quality and safety of urban environment, enhancement of community relationships, generation of positive revenue flows for long-term self-sustainability, etc.). Here circularity is linked also to avoided costs of abandonment and degrade of buildings and entire urban and landscape areas.

According to the general framework proposed within the Horizon 2020 "CLIC" project, cultural heritage adaptive reuse could be seen as an entry point to circular cities implementation, avoiding the 'waste' of resources by reusing and regenerating buildings and sites which present functional obsolescence, and thus lost their original functionality (e.g. religious uses, productive uses, residential uses). This study adopts a concept of 'Circular Economy 2.0' (Lemille, 2017), considering the implementation of CE principles in a sustainable development perspective which includes necessarily social and 'cultural' objectives along with environmental and economic objectives, overcoming approaches focused only on 'waste', materials, water and energy management. A cultural approach to CE, as adopted in this study, identifies multidimensional and multi-criteria indicators to assess the circular performance of adaptive reuse interventions in the historic built environment, in relation to key urban functions of the circular city/region:

1. The following levels have been developed within the CLIC Horizon 2020 Project. More info can be found at the following address: ***https://www.clicproject.eu/***.

DOI: 10.3217/978-3-85125-668-0-08

• **self-sufficiency of the city/region** (in terms of re-localization of production-consumption of energy, materials, food, water, and zero-waste strategies);

• **knowledge development and exchange** (towards globally connected, but locally self-sufficient cities and regions);

• **higher density of relationships** (promoting cooperation, synergies, symbioses between stakeholder, as well as between citizens through enhanced places identity).

The theoretical framework adopted is thus based on three levels of circularity in relation to three main objectives of a circular city/region. Once identified the theoretical framework, an inductive approach has been followed for the future identification of possible indicators able to show the relevance of cultural heritage adaptive reuse projects according to their contribution to circular city objectives.

Three representative adaptive reuse case studies have been analysed and are described below: De Ceuvel in The Netherlands, Rehafutur Engineer's House in France, and the Redock project in Spain, which represent different scales of implementation (Table 3). All three cases explicitly present themselves as experimentations of application of the CE model and can be linked to the three levels of circularity proposed above. Moreover, all the three cases focus their attention on the social and cultural impacts of the CE model adopted, and are thus suitable to explore circularity principles from a comprehensive perspective.

Name	**Country, City**	**Scale**	**Cultural heritage typology**	**Sustainability dimensions considered**	**Methodology of analysis**
De Ceuvel	The Netherlands, Amsterdam	Neighbourhood	Old boats, representing Amsterdam cultural identity	Environmental, Economic, Social, Cultural	Desk research and site visit
Rehafutur	France, Loos-en-Gohelle	Building	Historic villa, inside the UNESCO World Heritage Site	Environmental, Economic (savings), Cultural, Social	Desk research
ReDock	Spain, Altiplano Region	Village/ landscape area	Historic rural village	Environmental, Economic, Social, Cultural	Desk research and Skype interview

Table 3: *Case studies of circular economy implementation in cultural and lanscape heritage contexts*

A. GRAVAGNUOLO (1), R. DE ANGELIS (2), S. IODICE (1)
DOI: 10.3217/978-3-85125-668-0-08

It is necessary to specify that all three cases have been analyzed through a desk research. However, De Ceuvel's knowledge was also deepened through a guided site visit organized within the CLIC project, during which it was possible to interface with the case study managers. Finally, the description of ReDock is also the result of a Skype interview with the manager who allowed to deepen some circularity aspects.

3 Case Studies

1.1 *De Ceuvel*[1] *case study: an example of metabolic circularity*

De Ceuvel is a former industrial lot located in Amsterdam North that, through a series of transformations, has been turned into a sustainable area, thanks to the use of innovative technological solutions (Fig. 15).

The main peculiarity of De Ceuvel is represented by the use of retrofitted houseboats, linked to the Dutch culture and to the city of Amsterdam in particular, where they are generally used as floating houses. In De Ceuvel, in order to maintain this peculiarity, the boats have been located on the land and used as spaces with different functions for a period of ten years. Among the various uses, there is a floating bed and breakfast and a cultural venue. Furthermore, the area is characterized by the presence of a popular Cafè where there is a separate collection of urine (Roest *et al.,* 2016) and where an ecologically sustainable agriculture is adopted.

As the soil is polluted and it was not possible to create an underground infrastructure, these boats are provided with dry composting toilets, a heat pump, solar panels and biofilters for the treatment of grey water, while the use of phyto-remediating plants helps to clean the soil. The area has also what is called a “Cleantech Playground”, that is an ecosystem in which innovative clean technologies are tested, such as a composting plant, a struvite reactor and a greenhouse where the growth of vegetables is ensured by the use of compost and struvite. In addition, the following targets have been established:

1. The description on this case is based on the Report “TKI Loop-closure Cleantech Playground” and on a direct site visit within the Horizon 2020 CLIC Project.

DOI: 10.3217/978-3-85125-668-0-08

• 100% renewable heating and electricity supply;

• 100% on site wastewater treatment;

• 100% organic waste treatment;

• 100% on-site drinking water supply, if the legislative barriers for this are overcome[1].

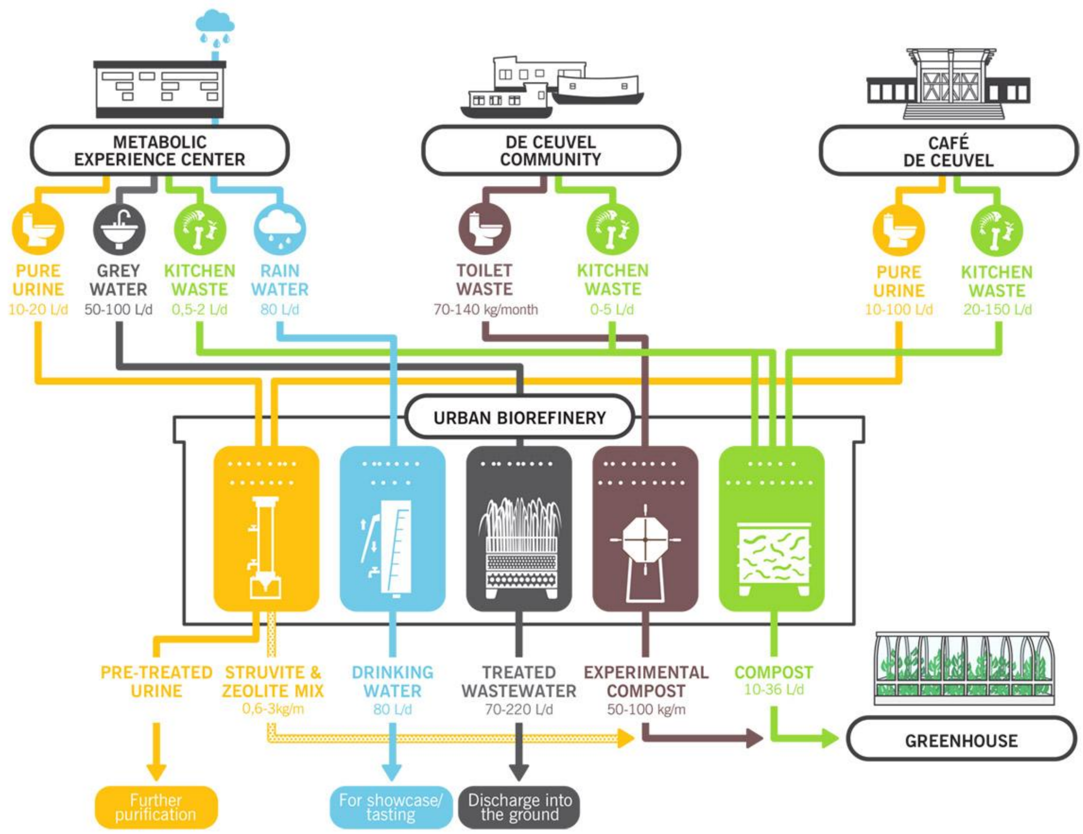

Fig. 15: *Sustainable technologies at De Ceuvel (source: https://www.metabolic.nl/news/opening-the-cleantech-playground/)*

These technologies have led to the creation of a sustainable workplace for creative and social enterprises, facilitating the development of a real community of entrepreneurs and artists, determining the formation of a cultural urban hub in which art, sustainability and technology coexist in a balanced way. Through the organization of events, workshops and lecture, the community is involved and can learn from De Ceuvel experience.

1. More information can be found at the following website: https://deceuvel.nl/en/

DOI: 10.3217/978-3-85125-668-0-08

The organization of the area allows the existence of different sources of income, like that related to the possibility of renting the site for one-day events. Other sources are represented by the possibility to use the warehouse and the gallery space as a plenary hall, as a workspace and also as a meeting room. Moreover, also the “Metabolic lab” as well as another space known as “Crossboat”, can be hired for the organization of creative events, workshops, courses and masterclasses for the practical learning about the technologies applied in the area, in order to enhance the awareness raising. It is possible to read that the rental price of the Metabolic lab for a full day is 550 € (excl. BTW). As already previously specified, another income comes also from the “Asile Flottant”, a collection of boats retrofitted as hotel rooms. These procedures have increased the involvement of the local community because all are leading actors in the transformation of the space and in the application of circular metabolic principles.

The technologies used are able to facilitate the closure of the cycles and allow the reduction of input and output resource flows, in line with the principles of circular Urban Metabolism (UM).

UM can be applied to different scales, so both to entire neighbourhoods like De Ceuvel, but also to individual buildings; indeed, as stated by Li and Kwan (2017), there are global UM studies as well as studies at the urban local dimension.

UM is currently characterized by a linear development model, causing an intensification of environmental impacts (EEA, 2015). The application of sustainable technologies in De Ceuvel allows the implementation of an efficient use of resources, facilitating the achievement of a circular metabolic model and of a local loop closure. Furthermore, the use of already existing boats with useful functions for artists, volunteers and entrepreneurs, allows reducing the consumption of raw materials for new buildings constructions.

This procedure is linked to the concept of “upcycling”, referred to the use of recycling components and second-hand materials coming from all over The Netherlands, facilitating landfill avoidance thanks to the re-use of sustainably retrofitted discarded houseboats that otherwise would have been demolished. These thirteen boats were taken out of the water and used for different functions, like offices, ateliers, spaces for events, etc. and they can be rent for creative and cultural purposes (Fig. 16). Definitely, the reuse process

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contributed to many circularity objectives, such as: the enhancement of energy efficiency, the reduction of water consumption, the reduction of raw materials extraction and of Construction and Demolition Waste (CDW) that would otherwise come from the boats dismantling.

Fig. 16: *Some houseboats at De Ceuvel (source: https://deceuvel.nl/en/)*

De Ceuvel is not only based on the implementation of an eco-design model through circular economy practices from an environmental point of view, but also on the construction of a community project with the integration of common knowledge and expert knowledge, demonstrating the possibility to reinvent people relationship with resources and involving future users in construction activities (Metabolic et al., 2014).

De Ceuvel is part of a redevelopment area called “Buiksloterham” located in the northern part of Amsterdam, that is being transformed from an industrial zone into a mixed used area that combines industrial, commercial and residential functions. An UM analysis has been executed in order to understand the functioning of the area from an integrated perspective, taking into account energy and material flows, biodiversity, socio-economic factors, environmental conditions, local stakeholders, policies and strategic plans, as well as the health and wellness of the inhabitants (Gladek *et al.,* 2014). This analysis considers the current state as well as a 20+ scenario and the following goals have been established:

DOI: 10.3217/978-3-85125-668-0-08

• fully renewable energy supply with mostly local production;

• zero waste neighbourhood with a nearly 100% circular material flow;

• rainproof and resource recovery from wastewater (almost 100%);

• regeneration of ecosystems and self-renewing of natural capital;

• flexible infrastructure design and zero emissions local mobility;

• diverse and inclusive culture, and high liveability metrics;

• strong local economy that stimulates entrepreneurship and the creation and exchange of multiple kinds of value (social, environmental, cultural);

• healthy, safe and attractive environment with recreational activity space for all residents.

In order to achieve the above goals, an inclusive governance structure is necessary with the purpose of including both large and small stakeholder through the organisation of bottom-up initiatives. As far as the financial vehicles and the incentive systems are concerned, the following actions are proposed:

• establishment of a rotating investment fund;

• development and implementation of a local incentive system;

• establishment of reverse tenders for challenges and goals.

In general, through the integration of different resource flows and the development of smart financial scenarios, these projects yield a high return on investment and are financially feasible for the communities.

3.2 Rehafutur Engineer's House Case Study[1]

Rehafutur Engineer's House, a historical mining house in the Northern France UNESCO heritage site, is one of the sites included in the EU's project CAPEM (Cycle Assessment Procedure for Eco-impacts of Materials) aimed at assessing the effectiveness of renewable materials for insulation. Now converted into offices, the major intervention realised in the process of adaptive reuse consisted of improving the building thermal

1. The description of this case is based on secondary data (CE 100, 2016; Mangialardo & Micelli, 2018).

A. GRAVAGNUOLO (1), R. DE ANGELIS (2), S. IODICE (1)
DOI: 10.3217/978-3-85125-668-0-08

insulation. Due to its heritage value, the renovation of this building could not affect the external façade, meaning that retrofitting could only involve interiors, and reuse as much as possible of the existing materials was necessary. Using bio-based (e.g., wood fibre, sheep wool), and recycled (e.g., recycled textiles) insulating materials, high standards of energy efficiency have been achieved. In addition, to preserve the heritage value of the original construction, materials were reused. For instance, marble fireplaces have been used as ornaments in public rooms and 18 m^2 of multi-coloured cement tiles were also reused. For the characteristics of the renovation projects, i.e. the use of renewable insulation materials, high energy efficiency standards and reuse of materials, it can be said that Rehafutur Engineer's House is a pertinent example of the application of CE principles (adaptive reuse) in the construction industry. Several are the environmental, social and economic sustainability advantages resulting from the application of CE principles to this renovation project, which can be summarised as following:

• improved indoor air quality and comfort;

• reduced operating costs in the 'in use' phase: prior to the intervention the house needed 1,000 litres of fuel each year whereas after the renovation, the heating demand is very low at 34 kWh/m2 per year with environmental benefits too. In addition, given that the building is located in an area affected by issues of fuel poverty, this project has also a social value as it demonstrates how retrofitting could be effectively used to drastically reduce energy consumption;

• reduced materials costs (thanks to reuse of materials): reusing tiles rather than buying new ones has led to significant savings (8.000 €);

• employment opportunities: reduced materials bill has meant that more funds were available to employ more people, which was another plus of this project;

• the nature of the project kept construction workers motivated and proud to work on the site;

• the project involved a number of stakeholder (e.g., regional enterprises, universities and education centres) and so it had a relevant demonstrative impact.

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As it is possible to observe in the above information, the solutions adopted are able to reduce the flows of material and energy consumption, stimulating the implementation of a circular UM.

3.3 ReDock Project [1]

ReDock project (Fig. 17) is the transformation of a medieval village into a green and sustainable community, as part of a larger eco-restoration project in the region of the Altiplano, nearby Murcia in Spain. The village aims to become a blueprint for a sustainable future in the countryside and it is planned to be one of a series of green villages worldwide.

The project foresees the reuse and regeneration of the entire village and the surrounding rural area, developing a model of complete self-sustainability, in terms of energy, water, food, and even financial resources to conduct entrepreneurial and commercial activities through a cooperative, mutually supporting model enabling financial independence. Corporates, NGO-employees, government officials, researchers, teachers, start-ups, digital nomads, students and visitors are identified as final users.

The project has been developed by a Dutch company in close cooperation with interested stakeholder such as potential users and investors. An initial investment of 250 K € was granted by private funders, enabling the start-up and detailed design of the ‘closed’ metabolism and key functions of the village. The functions cover the needs of a self-sustaining community oriented to experiment innovative models and lifestyles in line with CE principles.

1. The description of this case is based on secondary data retrieved from ***www.redock.org*** and on primary data from an in-depth interview with the manager and designer of ReDock, conducted via web meeting in 2018.

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Fig. 17: *ReDock village design in Spain (source: www.redock.org)*

The regeneration of natural capital, currently extremely reduced in the Altiplano region due to over-exploitative industrial and farming activities, is the key objective of the ReDock project. The Altiplano region, that was in the past a highly bio-diverse and fertile area, presents itself today as a large arid land, requiring 2 Billion Euro to be brought back to natural conditions suitable to life of natural species and human communities. Starting from the recognition of the multiple and complex interrelationships between communities and the ecosystems in which they settle, the eco-restoration of the Altiplano becomes the key objective: the regeneration of land and other natural resources that enable and support human activities. The adoption of multifunctional farming systems enables thus not only local production and consumption of food, but it also aims to regenerate soil fertility over time, as well as conserving and increasing freshwater sources.

The medieval village is recovered enabling new functions that respond to contemporary needs, avoiding the ‘nostalgic’ idea of the traditional village functions and enabling a contemporary way of living in the countryside. This means to generate new use values for abandoned buildings and sites, which can be transformed into market values re-generating local economies. The plan foresees the realization of Hotels, a School of eco-restoration, an Info-center for visitors and residents, Start-ups co-working spaces, Offices distributed in the entire village and even open-air, Sports facilities, Services such as cultural and social activities (Workshops, Events). The adaptive reuse strategy applies to all parts of the village: churches will be transformed into schools, stables into offices, etc. Temporary living is actively promoted, opening the village to a larger international community of innovators, who may find a place to exchange knowledge and experiment different ways of life and work. Circular flows of materials, energy and water are designed as part of the ‘closed’ metabolism of the village. Food is grown in the local area, a photovoltaic park connected to the village own energy grid has been designed. Every wasted material is reused to become resource for other productive processes.

The research of ReDock project is focused on providing opportunities for healthy and flourishing life. Decent and attractive work conditions are at the core of this strategy: offices are designed to ensure comfort, flexibility, and to enhance creative work enabling strong connection of people to nature. Healthy food is grown locally and served in the restaurants, which establish agreements with local farmers. Health, creativity, innovativeness, wellbeing, are key concepts of CE that are applied in the ReDock project.

This model of self-sustainability should not be intended as a tentative of ‘isolate’ the local community through ‘off-the-grid’ technological measures. On the contrary, the village aims to be connected through physical and digital means, particularly through high-speed internet connection serving the whole area. Data collection on different metabolic flows represent a key source of knowledge to continuously improve the functioning of the village.

Considering the features of the ReDock project, it is possible to recognize three main aspects that enable a CE model in the reuse of historic rural villages:

• a cooperative and mutually supportive financial system;

• a business model based on re-localization and synergic/symbiotic value chains in the area;

• a self-sufficiency objective and the regeneration of natural capital, built capital, human and social capital.

The next section synthesizes the key aspects of circularity that can be recognized in the experiences analysed, applying the three-levels framework previously proposed.

4 Discussion: Key aspects of circularity in the analysed case studies

The three levels of circularity (Gravagnuolo et al., 2017, 2018) that have been proposed in chapter 2, are now associated to the three analysed case studies, in order to understand how they reach the circularity objectives:

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• **cultural values conservation/regeneration**

In **De Ceuvel** this happens because the boats in their configuration are linked to the Dutch cultural values. Furthermore, the organization of events like interactive workshops, concerts and conferences, and the rent of the boats for different functions help improving the communications of the sustainability values that De Ceuvel wants to reach. In **Rehafutur** this happens because the reuse process has contributed to the conservation of tangible and intangible heritage values and finally in **Redock** because the reuse project regenerates natural and cultural heritage and landscape, providing also additional educational and demonstrative values.

• **Circularity of conservation interventions**

In **De Ceuvel** this is clearly evident in the healthy UM that has been achieved thanks to the combination between urban agriculture, small-scale renewable energy technologies, local urban food production, biological water purification systems, and so on (Gladek and Monaghan, 2013). It is possible to state that the reuse process contributed to many circularity objectives. In **Rehafutur** this is achieved thanks to the technical choices of adaptive reuse and finally in **Redock** through the development of a self-sustainable energy and food system recovering traditional agricultural farming techniques mixed with efficient technological solutions (e.g. renewable energy grid, digital technology).

• **Circularity of outcomes coming from reuse initiatives**

This third level in **De Ceuvel** is achieved through the development of smart financial scenarios (Roest et al., 2016). First, among the sources of income, there is the activity related to Cafè De Ceuvel and also that related to the boats rental. In addition, among the key features of the project, there is also a fast return on investment thanks also to the use of Do It Yourself (DIY) approach. Moreover, the project enhances the creation of jobs, the attractiveness for innovative start-ups and companies, for cultural and creative industries as well as commercial activities, improving also the whole attractiveness of the area, that has become a popular example of tangible sustainability. In **Rehafutur** this is achieved thanks to the increased attractiveness and to the employment opportunities and finally in **Redock** through the attractiveness for creative and innovative entrepreneurs, new jobs in rural areas, new jobs in digital technology and the regeneration of rural ecosystems at a larger scale.

Table 4 summarizes the CE impacts in the three analysed cases, providing insights for the subsequent identification of possible indicators of circularity to assess adaptive reuse interventions in the historic built environment.

Case study	**Cultural values conservation/ regeneration**	**Circularity of conservation interventions**	**Circularity of outcomes coming from reuse initiatives**
De Ceuvel	Educational activites; Demonstrative actions (awareness raising); conservation of manufactured goods related to the Dutch culture (boats); communication of heritage values.	Closed cycles of energy, water, materials, organic materials and waste.	Attractiveness of the area for creative and innovative entrepreneurs/firms; social activities; community-building; circular financial system (local currency, Buikslotherham incentives and revolving fund), etc.
Rehafutur	Tangible heritage values conservation; demonstrative project (awareness raising); Pride.	No waste of materials; reuse of materials and objects; energy efficiency systems; recycled and renewable materials.	Attractiveness of the experience as demonstrative project; example for local owners and community; employment opportunities.
ReDock	Landscape heritage regeneration; traditional farming conservation; recovery of abandoned heritage buildings.	Own renewable energy grids; water and materials reuse; digital infrastructure.	Attractiveness for residents (even temporary), visitors, creative and innovative entrepreneurs, digital workers – through natural and cultural heritage regeneration; healthy environment and lifestyle; sustainable financial system and business model, etc.

Table 4: *Comparison of circular impacts in the three analysed case studies, applying the three-levels methodological framework*

5 Conclusions

The three case studies show that experiences of cultural heritage adaptive reuse from CE and UM points of view are already in place and can inspire the development of an emerging sector of implementation within CE applied to the historic built environment. However, a monitoring and performance assessment framework is still lacking in this

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sector. Building construction industry metrics still do not monitor the "circular" performance of interventions in existing and historic buildings, while CE is recognized as an opportunity for construction industries (ECSO, 2018; EMF, 2016; ARUP, 2018; Bruxelles Environment, 2018; Gravagnuolo et al., 2019). Moreover, it is still controversial to identify common indicators able to show the circular performance in multiple dimensions: social, economic, environmental, and cultural. The three case studies show a high variability of impacts, which suggests that a common ground for the assessment of 'best practices' and the orientation towards CE should be found through exploration of theoretical concepts together with concrete experiences, in order to develop evidence-based knowledge of the real impacts of CE-led interventions in heritage contexts.

The three levels of circularity described in this paper have been identified in the Horizon 2020 CLIC project in order to develop a matrix of indicators for the multidimensional impact assessment of adaptive reuse of cultural heritage projects. This matrix is part of Work Package 2, that has the aim to evaluate and compare the impacts of systemic adaptive reuse in the environmental, cultural, social and economic dimensions through the identification of suitable criteria and indicators in the CE perspective. In addition, some more indicators will be introduced with reference to the specificities of the cases under analysis. The concept of Urban Metabolism and Metabolic Impact Assessment lends itself well to being used for the implementation of a methodological framework for the assessment of urban performances in the perspective of CE. This metabolic analysis could be able to combine the multiscalarity that inevitably characterizes the impacts of adaptive reuse of cultural heritage.

Indicators in general are essential tools as they allow to summarize complex information on the territorial functions and to represent certain aspects concerning the state of the environment (built or not) from a multidimensional point of view, monitoring and analysing the territorial flows (Fry et al., 2009). Future developments, in line also with CLIC advances, will consist in the identification of a set of core indicators to guide the impact assessment of cultural heritage adaptive reuse at different geographical scales (micro, meso and macro) and from different points of views (manager organizations/local governments).

Definitely, only through the development of scientific measures, it is possible to monitor and identify common rules able to close the loops and to reduce the input and output metabolic flows.

Authors contribution

The authors have worked in strict collaboration to develop the concepts and methodological approach to this study. Specifically, Antonia Gravagnuolo designed the work and developed the introduction, the methodological framework expressed in Section 2, the case study of ReDock and the overall analysis of circular impacts in Section 4. Roberta De Angelis developed the literature review on circular built environment and circular business models in the building construction sector, as well as the case study of Rehafutur. Silvia Iodice developed insights on Urban Metabolism and the case study of De Ceuvel. The authors have contributed equally to the development of discussion and conclusions.

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