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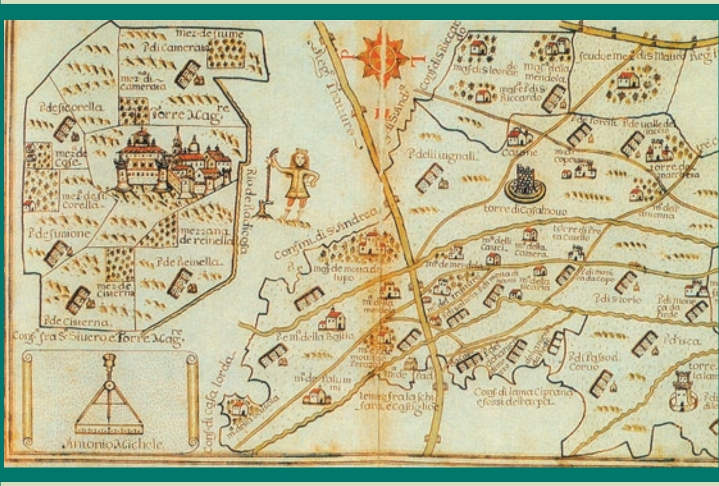
Sustainable development and circular economy



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Keywords: *Life Cycle Cost Benefit Analysis, Maintenance Costs Planning, Infrastructures Durability*

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A life cycle perspective for infrastructure management §

Circular Economy, founded on the self-generative economic system concept, can be traced back to the Life Cycle Thinking, that conceives the project as a process along its whole life cycle, at the different scales: material, component, system, building, urban district and territorial area, infrastructure. In Italy, as in the main part of European Countries, a great portion of infrastructures was built in reinforced concrete before 1960 and is approaching the end-of-life stage. Thus, aim of this article is to propose an operative modality for supporting the preventive maintenance investments planning in function of life cycle costs and benefits, assuming the presence of uncertainty over time. Firstly, a recalling of the Cost Benefit Analysis (CBA) approach is presented. Secondly, the Life Cycle Cost Benefit Analysis (LCCBA) approach is proposed, as a tool for supporting long-term investments, management of public services and maintenance planning activities in the infrastructure sector. Thirdly, by integrating CBA and LCCBA, an operative modality is proposed. On the background, life cycle management, optimal maintenance planning and durability concepts are assumed.

1. Introduction

The Circular Economy principles can produce relevant impacts on production and consumption processes, not only in terms of raw materials and energy use in the construction sector, but also in terms of consumers' and producers' behaviour. This is in line with the aim to ensure sustainable behaviours in the construction processes, both in the private contexts and in the public ones, since the early design stages. In fact, as known, Circular Economy is founded on the self-generative economic system concept (the waste generated in a process, becomes a resource for another one), and it assumes the decoupling of economic development of a Country from the uncontrolled exploitation of natural resources. Thus, Circular Economy concept can be traced back to the theoretical approach of Life Cycle Thinking, that conceives the project as a process which develops along its whole life cycle, at the different scales: materials, components, systems, buildings, urban districts and territorial areas, infrastructures (European Commission, 2015).

In the international context several associations are promoting the transition to the "from cradle to cradle" economic model. In Europe, companies such as the British Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2012; 2015), allowed European Commission to promote the Circular Economy in its Commu-

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nity policies (European Commission, 2020). In Italy, acknowledging the principles of Circular Economy, the "real estate appraisal and project evaluation" discipline plays a fundamental role in the scientific debate, by providing economic evaluation methodologies which are rapidly evolving towards the international policies on sustainable development. In fact, at the time being the economic evaluation of projects covers a broad spectrum of procedures recently opened to the life-cycle approaches. This spectrum results from the scientific research evolution process, by incorporating the external changes in economy, society, and environment, and it is constantly related to the international regulatory/policies framework which involves the construction sector.

Recently, the estimative research opened up to the energy and environmental impacts assessment beside the economic ones, as decision criteria for selecting project technological alternative scenarios and for supporting the economic management in construction processes, with a view to the Life Cycle Thinking principles (König et al., 2010). Despite the considerable efforts in growing the literature and the empirical studies, a prevailing attention seems to be posed at exploring the life-cycle models for economic-energy-environmental evaluation in the private context. The focus of the disciplinary debate is posed on the implementation of methodologies for evaluating energy retrofit projects of existing buildings or high performance new built construction projects, opening to the use of economic and environmental life cycle approaches, such as Life Cycle Cost Analysis (LCCA) (ISO 15686-5:2008; ISO 15686-5:2017) and Life Cycle Assessment (LCA) (ISO 14040:2006), also through joint applications (see the literature review in Fregonara and Pattono, 2018).

Life-cycle methods in public projects evaluation seem less explored, exception for specific LCCA application contexts as the "green procurement" one (this last is illustrated in Langdon, 2007).

Thus, there are still several research opportunities for developing long-terms evaluative methods able to model costs and benefits in economic, financial, environmental and social terms, according to the recent holistic view of "global sustainability".

With these premises, among the topics highlighted for this Special Issue of *Aestimum*, the evaluation of social and environmental benefits and costs of production systems, according to the Circular Economy perspective and in relation to their economic sustainability, seems an interesting challenge under the evaluative-estimative viewpoint. This implies the rethinking of consolidated socio-economic evaluation tools, by introducing life cycle principles.

Among the contexts of analysis, in this work focus is posed on the infrastructural sector, for some relevant motivations. In fact, in Europe, a great portion of infrastructures was built in reinforced concrete before 1960 and is approaching the end-of-life stage, or has reached the end of its service life; in some cases, the service quality is below the acceptable level, and the state of conservation is highly weak (Farhani et al., 2018). The issue of infrastructure maintenance deserves great attention from the scientific communities involved, even if – as highlighted by (Farhani et al., 2018) – at the time being the maintenance culture is rather weak.

In Italy, analogously with the main part of European countries, a large number of infrastructures has similar conditions. For these reasons, there is an urgent necessity to promote strategic management, also through the planning of maintenance activities, calibrating different degrees of intervention in view of the work conditions (light ordinary maintenance intervention, main maintenance intervention, repair, replacement, or demolition and reconstruction).

From these premises, the aim of this article is to propose a methodology for supporting infrastructure management and investment decisions in maintenance planning, assuming a consolidated approach for public projects evaluation – the Cost Benefit Analysis (CBA) – and a recent implementation of LCCA approach – the Life Cycle Cost Benefit Analysis (LCCBA) – and integrating them in a life cycle perspective.

The work develops in three parts: firstly, a synthetic recalling of the "classic" CBA approach is presented (Eckstein, 1957, Marglin, 1963; Mishan, 1974; Pearce, 1971; Pearce and Nash, 1981). Originally applied for evaluating (among the others) infrastructural projects, and, successively, widely explored in public resource investment and in cultural heritage enhancement projects, the approach represents one of the most consolidated models for the socio-economic evaluation of public projects. Secondly, a brief introduction to the LCCBA approach (Thoft-Christensen, 2004, 2006, 2008, 2009, 2012) is proposed, as a tool for supporting long-term investments, management of public services and maintenance planning activities in the infrastructure sector (bridges, roads or highways). The approach, relatively recent, is poorly explored despite its potentialities as a tool for testing the economic sustainability of public projects in a life-cycle perspective, as an alternative to the standard CBA. Thirdly, on the basis of the CBA and LCCBA formalization, an operative modality is illustrated, specifically on the use-maintenance-adaptation phase in the infrastructures' life cycle.

Concluding the work, some open issues are highlighted to address future researches: the possible shift from the Global Cost calculation to the Annuity Method, as a tool to resolve the LCCBA; the service life estimate and maintenance time intervals definition, to guarantee the construction durability; the control of uncertainty components in model input/output data and over time. On the background, "life cycle management", "optimal planning maintenance" and "durability" concepts are assumed.

The paper is articulated as follows. In the section 2 the fundamentals of the Cost Benefit Analysis approach are recalled, according to the standard model. In the section 3 the life-cycle perspective in the evaluation of project sustainability is mentioned, through LCCA method and Life Cycle Cost/Whole Life Cost concepts. The LCCBA approach is synthetically presented, making reference to benefit and cost items detection in a social perspective. In the section 4 an operative modality is presented, for supporting investment decisions in infrastructure maintenance in a social, environmental, financial viewpoint. Finally, the section 5 concludes the article.

2. Cost Benefit Analysis: the socio-economic perspective

To frame methodologically the CBA, it would be necessary to retrace the literature on topic. Considering the vastness of the contributions produced in the decades by the scientific communities, and considering the aim of this paper, a synthesis of the approach is traced, as a tool for supporting the evaluation of public projects economic feasibility (Eckstein, 1957, Marglin, 1963; Mishan, 1974; Pearce, 1971; Pearce and Nash, 1981).

In the evaluative context, the set of the commonly used procedures at the various scales is articulated upon their methodological nature. As known, the approaches are related, alternatively, to the asset/property/resource/project subject to evaluation and differenced according to their public/private nature. CBA is one of the evaluation techniques for testing the feasibility of intervention projects on public assets/resources (architectural, cultural and environmental). It is based on economic-quantitative criteria expressed through a monetary unit, and on synthetic indices of economic profitability, which are capable to measure the "economic value of a project" according to which to accept/exclude alternative project options. Furthermore, CBA is one of the decision-aiding tools for dealing with scarce resources issues.

Recalling well-known aspects, the aim of the technique is verifying the economic feasibility of a project, and, according to the estimative viewpoint, it is included within the scope of the "economic convenience judgments". Synthesizing, the fundamental aspects of CBA are: the transition from financial to economic analysis, the costs and benefit classifying modality, the pricing system, the financial discounting, and the calculation of (financial and economic) profitability indicators. The fundamental difference between financial and economic analyses is that any investment of capital represents a different convenience according to the project promoter. In fact, costs and benefits value is variable in view of the stakeholders that receive benefits/pay costs. Notice that the financial analysis is aimed at evaluating the effects of the project from a financial viewpoint, considering into the model only the input directly quantifiable in monetary terms; therefore, it is carried out from the investor's viewpoint. On the opposite, the economic analysis considers also the effects non directly quantifiable in monetary terms, such as effects on environment, or effects on society and economic activities indirectly involved by the project. In this second case, the analysis is carried out from the collectivity viewpoint.

Operatively, the analyses differ according to the costs and benefit considered. In the financial analysis, financial costs and financial incomes are modelled. Otherwise, the economic analysis considers: financial costs calculated through shadow prices, plus opportunity costs calculated through lost revenues obtainable from the best alternative investments; environmental costs quantified as environment damages or negative externalities; then, financial incomes plus social benefits or positive externalities. Furthermore, they differ according to the prices system adopted: market prices for financial analysis and shadow prices for the economic one. Notice that shadow prices should represent the fair appreciation from society expressed in terms of willingness-to-pay (or, better, capability-to-pay) for a good or a service (Pearce, 1971). In fact, market prices are not always capable to reflect the actual consumers' willingness-to-pay. Furthermore, and, above all, some market prices do not reflect the system of social priorities in place at the time to which the project refers. The divergence between market and shadow prices founds on the divergence between economic and political judgment, and their different evaluation perspectives: all these issues are extensively dealt with through the Welfare Economics.

According to the Welfare Economics theories, costs and benefits of a public project are defined in terms of "social costs" and "social benefits". Respectively, social costs and benefits are defined by summing two components.

The social costs are the sum of financial costs (in other terms, a component related to costs directly quantifiable in monetary terms, for example construction costs necessary for the execution of the work), and externalities (a second eventual component, represented by costs not directly quantifiable in monetary terms, such as environmental damages due to execution of the work, or the goods and services which must be renounced for the project realization). The social benefits, similarly, are calculated by summing a first financial component named financial revenues (directly quantifiable in monetary terms) obtainable by the project, and a second component named positive externalities eventually present (not directly quantifiable in monetary terms, for example, goods and services provided by the project which increase the well-being of the community). Thus, the differences between social costs and benefits are mainly represented by the presence of, respectively, negative/positive externalities, and more precisely the positive or negative alterations of the utility without the payment of money.

Social costs components are deeply treated in literature (see for example Pigou, 1932; Coase, 1960, Pearce and Nash, 1981).

Operatively, for defining costs the concept of opportunity-cost is used, whilst for defining benefits the concept of willingness-to-pay is adopted (which in turn is resolved through the shadow prices system, or through the consumer's surplus calculation, or other methods), since, as said before, market prices do not reflect the actual willingness-to-pay. Notice that all this applies if costs and benefits are detectable, otherwise the closest to them are used.

It is still worth reminding that the benefit determination can be reinforced by the Total Economic Value, which components –Vicarious Value, Option Value, Bequest Value, Existence Value- can be calculated through appropriate techniques and thus modelled as benefits into the economic analysis of the CBA (among the founding contribution on the Total Economic Value theory, see Boyle and Bishop, 1985; Krutilla, 1967; Weisbrod, 1964). These appropriate techniques consist mainly in approaches explored for public assets assessment, such as the direct methods founded on hypothetical markets (e.g. Contingent Valuation Method and its variants), or indirect methods founded on substitute markets (e.g. Travel Cost Method, and Hedonic Prices Method). Thus, for CBA environmental and health impacts are internalized into the model.

Furthermore, a line of research develops towards the conjunction of CBA with Impact Analysis for evaluating the costs/benefits streaming from the project to the stakeholders and social groups involved, on the basis of the Lichfield's Community Impact Evaluation methodology (Coscia et al., 2015; Torre et al., 2017).

Coherently with the generality of models, input data detection and quantification is a crucial step in CBA: the robustness of the analysis results is in view of input data quality. In literature, attention is given firstly to the possible classification of CBA input items (costs and benefits). For example, a common classification distinguishes cost items between primary costs (construction or reconstruction cost, use and maintenance of the whole project), secondary costs (cost for product transformation and marketing), indirect costs (costs for other investments feasible or necessary due to project realization), intangible costs (not directly quantifiable in monetary terms). As concerns benefit items, a distinction is made between principal benefits (e.g. increase in surplus value, reduction in costs for the project implementation), and secondary (e.g. increases in surplus value, lower costs for economic activities correlated to the project), indirect benefits (e.g. higher wage incomes), and intangible benefits (not directly quantifiable in monetary terms).

A further distinction is made between direct costs and benefits, which are the investment and running costs that compete to the subject responsible of the execution and management of the investment work, and indirect costs and benefits, for investment and running, that compete to other subjects. These last can furtherly be articulated in cost items related to collateral works, necessary to the functioning of the work under evaluation, costs related to economic activities induced by the intervention, and, finally, externalities. Notice that the investment costs are referred to the public work execution and to the induced/derived works, including renewals, replacements, and extraordinary maintenance. Whilst running costs are referred to cost items for the management of the public work and induced/derived ones, including ordinary maintenance costs.

To conclude this section, it is worth mentioning that one commonly used synthetic profitability indicator, in financial and economic analyses, is the Net Present Value (NPV). It indicates the discounted project value calculated through the discounted sum of the net cash-flows, both in relation to the financial analysis and to the economic one. Still in a temporal perspective, the NPV is accompanied by the Internal Rate of Revenue (IRR), which indicates the rate that makes the value of the investment equal to the initial cost (maximum weighted remuneration/risk), and, finally, the Discounted Benefit/Cost Rate which indicates the benefit amount against the total cost, when comparing alternative projects.

Formally, as reported in the literature, the NPV can be expressed as in Equation (1):

$$NPV = \left(\sum_{i=0}^{N} \frac{B_p}{(1+r)^t} - \sum_{i=0}^{N} \frac{C_p}{(1+r)^t} \right) - \left(\sum_{i=0}^{N} \frac{B_{wp}}{(1+r)^t} - \sum_{i=0}^{N} \frac{C_{wp}}{(1+r)^t} \right) \quad (1)$$

where: B_p stands for the benefit in presence of the project, C_p stands for the costs in presence of the project, B_{wp} represents the benefits in the hypothesis without intervention (or conservation scenario), C_{wp} the costs in the hypothesis without intervention, r stands for the discount rate and, finally, N represents the lifespan of the analysis.

The Equation (1), as reported in the literature, can be rewritten as follows, where NB_p stands for the net benefits with intervention and NB_{wp} stands for the net benefits without intervention:

$$NPV = \sum_{t=0}^{N} NB_p \cdot \frac{1}{(1+r)^t} - \sum_{t=0}^{N} NB_{wp} \cdot \frac{1}{(1+r)^t} \tag{2}$$

Despite the simplicity of the formula, the input calculation is complex. A wide literature is devoted to the costs and benefits calculation, specifically for the external components, and the discount rate determination is still an open issue. More demanding is quantifying the social cost and benefit components by means of shadow prices or other alternative methods: for example, it is usually difficult defining the boundaries of the territorial basin within which to quantify costs and benefits, in particular the indirect ones (i.e. costs and benefits induced by the realization of a project). As concern the discount rate, in general, this is conceived in terms of public discount rate, or cost-opportunity rate, or social rate of time preference, and it is normally assumed lower than the private one.

Finally, the project lifespan determination is another delicate step, due to the long time horizon in public projects evaluation and its direct impact on the discounting operation. The service life, which represents the "economic life" of the project, is another crucial point of the analysis. In some case it is defined as the timespan beyond which the net marginal annual benefit, discounted to the initial year, produces irrelevant increases in the net economic present value. A suggested solution, among the others, is to adopt weighted time horizons on the basis of the relevance of the yearly discounted values (also with the support of reference thresholds).

In conclusion, for reminding the base rule to support the decision-making processes, even in the case of infrastructure projects (as roads, highways or bridges), the net benefits must be higher than the costs, considering that the net benefits must also be higher than the net benefits obtainable through any other alternative use of the capital considered for the analysis. Notice that, when in presence of environmental/social damages, cost estimation is the core of the evaluation and decision process. Then, it is worth notice that CBA founds on incomes and outcomes cash-flows according to the Discounted Cash Flow Analysis Anglo-Saxon approach, moreover object of advanced application in private-public partnership interventions (Tajani et al., 2019). The financial flows stream over a project time horizon that covers the design, execution and management stages, differently from the circular view illustrated in the next section.

3. Life Cycle Cost Benefit Analysis: the "circular" perspective

The LCCA, or Life Cycle Costing (LCC) approach, is widely studied in the literature (Department of Energy, 2014; Flanagan, 1983; Langdon, 2007). As said before, LCCA is normed by the Standard ISO 15686:2008, revised by ISO 15686-

5:2017. In Italy, as a decision criterion it is introduced on April 18, 2016, through the Legislative Decree no. 50, implementing Directives 2014/23/EU, 2014/24/EU and 2014/25/EU of the European Parliament and European Council of 26 February 2014 "on public procurement and awarding concession contracts, procurement by entities operating in the water, energy, transport and postal services sectors and on the reorganization of the Public Procurement Regulation" (New Code).

The methodology, aimed at evaluating the economic sustainability of projects favouring the assessment of project performance in terms of energy consumptions and savings, founds on the calculation of the Global Cost. This last, as indicated by the Standard EN 15459:2007 – Energy performance of buildings – Economic evaluation procedure for energy systems in building, revised by Standard EN 15459-1:2017, formally is expressed by the following Equation (3):

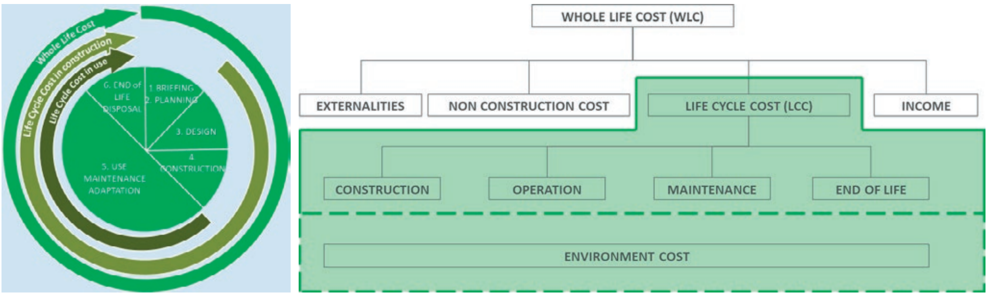
$$C_G(T) = C_I + \sum_J \left(\sum_{t=0}^{N} (C_{a,i}(J) . R_d(i)) - V_{fT}(J) \right) \qquad (3)$$

where $C_G(T)$ stands for global cost to the initial year T, C_I stands for initial investment costs, $C_{a,i}$ (J) stands for annual cost during year i of the component J (this cost item includes the annual running costs such as energy, operational and maintenance costs, and periodic replacement costs), R_d (i) stands for discount factor referred to the year i, finally $V_{f,T}$(J) stands for (eventual) residual value of the component J at the end of the project time horizon, referred to the initial year.

It is worth noting that, at the basis of the operative modality, the Life Cycle Cost concept is assumed. In Figure 1, left side, the life cycle phases in the construction process are graphically represented, as illustrated in the ISO 15686-5:2008, and, in the same Figure, right side, the Life Cycle Cost and the Whole Life Cost concepts are schematized.

As can be seen from the figure, Whole Life Cost and the Life Cycle Cost are different. The Whole Life Cost refers to the overall set of relevant initial/future costs/benefits, that come up in the course of the entire construction life cycle given specific performance requisites. In other words, the Whole Life Cost is a broad-

Figure 1. Life cycle stages in the construction sector. Life Cycle Cost and Whole Life Cost concepts (Source: Author's elaboration based on Standard ISO 15686-5:2008).



ened concept of cost, directed to include external factors (externalities), costs not directly related to construction, and incomes (for example, savings on management investments or "negative costs"). Instead, the Life Cycle Cost covers cost items of a project/component during its life cycle, to meet the performance required. Both consider some component of environmental costs, for two reasons. Firstly, the environmental costs are themselves streamed along the life cycle of the project. Secondly, both Whole Life Cost and Life Cycle Cost include energy costs (electricity/gas consumptions during the life cycle) which can be considered as a proxy of environmental negative impacts Notice that, in some cases, environmental costs can include also the Embodied Energy and the Embodied Carbon in each life cycle phase, quantified (through Life Cycle Assessment - LCA approach), and transposed into monetary terms.

The difference between the two cost categories is fundamental for the coming considerations.

According to our knowledge, the LCC analysis seems poorly explored in the context of public projects. Among the rare studies emerges the research conducted at the Aalborg University in Denmark (Thoft-Christensen, 2004, 2006, 2008, 2009, 2012). The research founds on the use of the LCC analysis, opportunely integrated, as a tool for supporting the management activities in the case of infrastructures (such as roads, highways, bridges, etc.), and, specifically, to support infrastructure maintenance planning.

The Thoft-Christensen's proposal founds on some preliminary theoretical/operative assumptions, synthetized below. In the case of infrastructures and considering their life cycle, the Author distinguishes the following three analytical approaches:

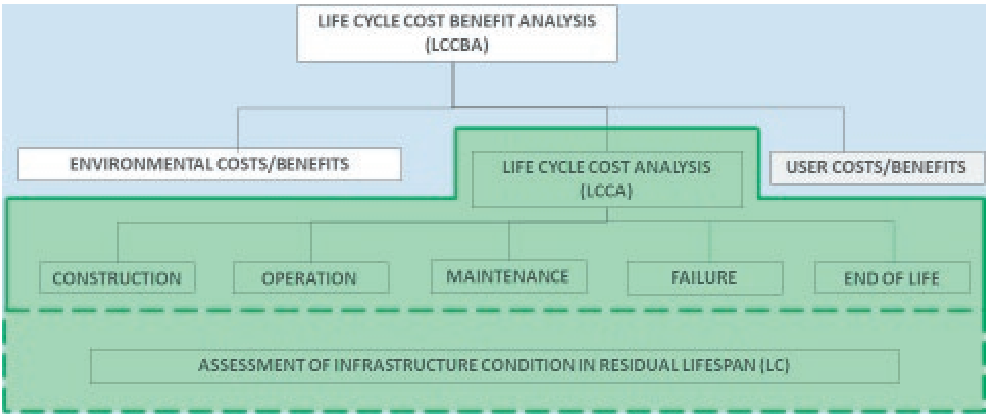
- LC - Life Cycle analysis. This is a simple assessment of the infrastructure condition in the residual lifespan (estimated maintenance costs, failure costs and environmental costs are not considered);
- LCC - Life Cycle Cost analysis (or LCCA). This is a LC analysis including estimated maintenance and failure costs;
- LCCB - Life Cycle Cost Benefit analysis (or LCCBA). This is a LCC analysis that includes also user costs/benefits and environmental costs/benefits.

As emerges from this first assumption, LCCB analysis is an "extended LCC analysis", in coherence with the difference between Life Cycle Cost and Whole Life Cost concepts traced before, in that Whole Life Cost category includes social and environmental costs/benefits (externalities).

Summing up, similarly to the Figure 1, in the following Scheme 1 the comparative difference between LC, LCC and LCCB is presented.

Operatively, LCCB analysis avails of benefits and costs calculated considering the whole life cycle of the project. Specifically, as illustrated in (Thoft-Christensen, 2012), the benefits are expressed by the sum of benefit components produced by the project in the society, for owners, users, and on the environment, as in the following Equation (4), in which the benefits are intended as net benefits:

Scheme 1. LCCBA, LCCA, LC Analyses. Schematic comparison.



$$LCCB = B_{society} + B_{owner} + B_{user} + B_{environment} \tag{4}$$

Similarly, costs are expressed by the sum of cost components produced by the project in the society, for owners, users, and on the environment, as follows:

$$LCC = C_{society} + C_{owner} + C_{user} + C_{environment} \tag{5}$$

Notice that the cost items in Equation (5) include, also, the costs items foreseen by the LCC analysis, distinguishing and spreading the parts that fall on the different subjects/contexts (society, owner, user, environment). For example, maintenance and failure costs compete to owners, but the negative effects deriving from a maintenance intervention (translated in monetary terms for example by quantifying the costs due to the working time losses) compete to users.

Then, notice that these components are to be intended as expected values, assuming the presence of uncertainty (as will be discussed in the section 4 of the present paper).

It is useful to point out that the owner cost/benefit items are deeply studied in the consolidated literature related to the evaluation of life cycle projects in the infrastructure sector, whilst society and user cost/benefit components (direct and indirect) are less explored. Thus, the recent research is highly focused on user costs estimation, for compensating the gap in the literature but above all for the following motivations (Thoft-Christensen, 2012):

- firstly, user costs can be (even sensibly) higher than the total costs, and therefore it is not methodologically acceptable to omit their calculation;
- secondly, the cost items estimation frequently allows benefit calculation (at lease in relation to some specific item), in terms for example of savings, negative costs, avoided costs, etc.

Similarly, the environmental cost/benefit components are particularly difficult to assess. The following aspects are to be considered:

- usually, environmental costs/benefits are treated in terms of impacts due to emissions in the environment, waste production, consumptions, recycling and disposal, according to the Circular Economy and the Green Economy principles;
- other items – as traffic delays, time lost, disruptions, detours, etc. – must be considered, being deeply relevant for the evaluation process: these items can be sensibly higher than repair, maintenance and adaptation costs.

Despite the complexity, costs and benefits calculation is fundamental for supporting management strategies, which aim is to maximize the benefits and minimize the costs, both in the case of new built infrastructures and in the case of interventions on existing ones, for example after a structural assessment. In this last case, when input data on deterioration, repair intervals/cost amounts are available (for example from direct observations or experts' opinions), the maintenance strategy can be defined as illustrated by the Author on the basis of the following Equation (6):

$$\max LCCB = \max (B - C_{repair} + C_{user} + C_{environment}) \tag{6}$$

The Author continues with the implementation of an operative modality for supporting the decisions between alternative interventions (repairs), by optimizing the following (adapted) Equation (Thoft-Christensen, 2012):

$$\max_{t_R, n_R} \sum_{t=0}^{nL} (B(t_R, n_R) - C_{repair}(t_R, n_R) - C_{failure}(t_R, n_R) - C_{user}(t_R, n_R)) \tag{7}$$

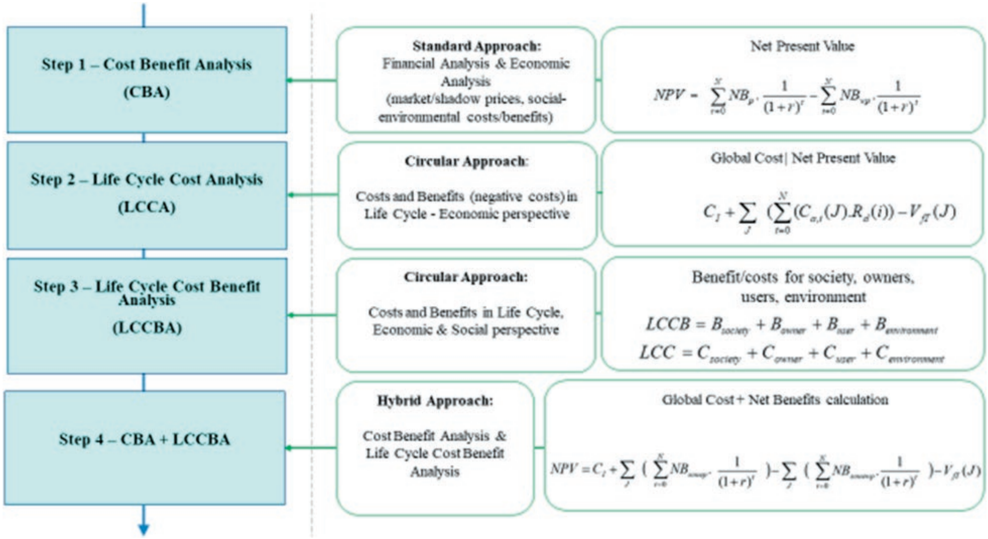
where n_R represents the expected number of repairs in the residual lifespan (first optimization variable), t_R represents the time of the first repair (second optimization variable), B represents the total expected benefits in the residual lifespan. The value of B, detracted the expected repair costs C_{repair} and the expected failure costs $C_{failure}$, both discounted at the initial time t=0, is to be optimized.

To conclude, notice that the literature demonstrates that costs for repair and/or failure of infrastructures are considerably higher than repair or replacement costs; furthermore, that user costs are higher than repair costs. These costs are directly related to maintenance planning strategies and investments: thus, these last must be minimized not only in relation to the owners' component but also to the users' one. This justifies the use of LCCB analysis in the evaluation and planning of infrastructure interventions.

4. An operative modality based on CBA-LCCBA for infrastructure management

To support the reading of the work, the graphic abstract illustrated in the following Scheme 2 may be useful. In the scheme, the methodological steps are summed up.

Scheme 2. The methodological steps of the proposed operative modality. Schematic abstract.



According to the classic CBA model, the economic and financial analyses are solved through the calculation of synthetic financial/economic indicators, above all the NPV and the IRR. As said in section 2, the NPV is calculated by hypothesizing the scenario "with intervention", and the scenario "without intervention" (or "option zero"), for testing the acceptability of an investment. When in presence of alternative project options, the NPV supports the preferability ranking of alternatives. Through an intergenerational approach future generation impacts in terms of costs and benefits are included in the model, by monetizing the effects potentially produced by the intervention on environment, society, economy, culture, according to a broad concept of feasibility.

As highlighted in section 3, Circular Economy and Life Cycle Thinking principles introduce a more complete perspective for treating the impacts/effects of a project over time, particularly suitable for comparing technological scenarios under an economic viewpoint. Practically, the work breakdown of the alternative scenarios is fundamental for the cost/benefit assessment.

Following the LCCBA idea, the project/intervention preferability can be calculated by the difference between benefits and costs produced by the project/intervention during its life cycle (or during the residual lifetime), as in the following Equation (8):

$$LCCBA = LCCB - LCC \tag{8}$$

The acceptability of a single investment is verified through the positivity of LCCBA; the highest LCCBA represents the preferable alternative project, when in presence of a set of project options. Considering the Equations (4) and (5) illustrated in the previous section, the Equation (8) can be rewritten as:

$$LCCBA = (B_{society} + B_{owner} + B_{user} + B_{environment}) - (C_{society} + C_{owner} + C_{user} + C_{environment}) \tag{9}$$

Evidently, the presence of social costs/benefits, negative/positive impacts on users and environment due to the intervention represents a fundamental difference between LCCA and LCCBA; thus, as said before, LCCBA can be defined as an "extended" and more complete LCCA, likewise the Whole Life Costing approach.

Considering a single intervention, for example the repairing of the road paving as a part of a maintenance work, the Equation (1) integrated by Equation (9) can be rewritten as follows:

$$\begin{aligned} NPV = & \left(\sum_{t=0}^{N} \frac{B_{p_{society}} + B_{p_{owner}} + B_{p_{user}} + B_{p_{environment}}}{(1+r)^t} - \sum_{t=0}^{N} \frac{C_{p_{society}} + C_{p_{owner}} + C_{p_{user}} + C_{p_{environment}}}{(1+r)^t} \right) + \\ & - \left(\sum_{t=0}^{N} \frac{B_{wp_{society}} + B_{wp_{owner}} + B_{wp_{user}} + B_{wp_{environment}}}{(1+r)^t} - \sum_{t=0}^{N} \frac{C_{wp_{society}} + C_{wp_{owner}} + C_{wp_{user}} + C_{wp_{environment}}}{(1+r)^t} \right) \end{aligned} \tag{10}$$

This last formula, according to Equation (2) and to Equation (3), can be rewritten as follows:

$$NPV = C_I + \sum_J \left(\sum_{t=0}^{N} NB_{souep} \cdot \frac{1}{(1+r)^t} \right) - \sum_J \left(\sum_{t=0}^{N} NB_{souewp} \cdot \frac{1}{(1+r)^t} \right) - V_{fT}(J) \tag{11}$$

This formula represents a "hybrid procedure", being obtained by integrating the NPV calculation according to CBA approach and the NPV (or Global Cost) calculation according to LCCA. Once verified the positivity of NPV, the preferability of the alternative options is assigned according to "the highest the best" NPV value.

Recalling the above mentioned example, the initial investment costs are not included, being the evaluation referred to the use-maintenance-adaptation phase in the infrastructure life cycle, with a repair intervention at a certain point in the lifetime of the construction.

Despite the simple change made to the calculation modality, the potentialities are remarkable. Nevertheless, the effective applicability of the procedure depends on some operative issues which must be furtherly explored as will be traced below.

4.1 Global Cost vs Annuity Method

As known, the norm EN 15459:2007/2017 illustrates two alternative modalities for calculating the energy performance in the building sector: Global Cost and the Annuity Method. The first one is widely explored in the literature, being the fundamental of LCCA, even in the infrastructure sector (Paganin et al., 2020), whilst the second one is poorly studied, at least to our knowledge. Among the rare studies on the second approach, can be also mentioned applications in the road pavements context (Diependaele, 2018).

The Annuity Method, or Equivalent Annual Cost approach, is based on the calculation of the annual costs of a building/system/component, through the combination of all the relevant costs into a single annualized mean cost, by means of the annuity factor a(n). Substantially, this last is the reciprocal of the discount factor, or the "present value of the discount factor". Formally, the Annuity Cost can be expressed as in the following Equation (12):

$$AC = C_r + \sum_i (a(i).\sum_j V_0\ (j)) + \alpha(\tau\_{Building}).(\sum_j V_0\ (j)) \tag{12}$$

for j, where τ (j) = i < t _ Building for j, where τ_n (j) ≥ t _ Building

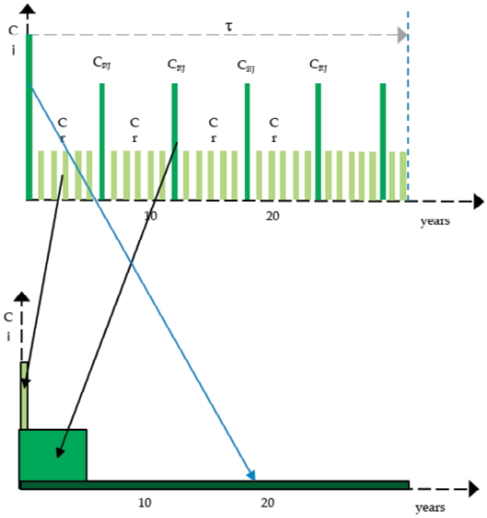
where AC is the Annuity Cost, C_r is the annual running cost (energy, operation, maintenance, etc.) yearly distributed, Σ(a(i).(Σ V_0(j)) is the total annualized cost related to j components/systems replacement, when the service life is lower than the building life cycle, α(τ_Building).(Σ V_0(j)) is the total annualized cost related to j components/systems replacement, when the service life is unchanged during the building life cycle, being the life cycle longer than the building's one, Σ(a(i) is the annuity factor when the component service life is lower than the building life cycle, α(τ_Building) is the annuity factor when the component service life is longer than the building service lifespan. Notice that the whole Equation (12) is describing the Annuity Cost for a single building/system/component, thus the expression (τ_Building) is referred to the single building lifespan considered for the calculation, and compared to the system/component lifespan.

In the formula, the cost components are summed – not discounted –, and the yearly costs are supposed constant (see the schematic example in Figure 2).

The method, particularly in presence of alternative technological scenarios, can effectively support the preferability ranking of projects. The lowest Equivalent Annual Cost is the preferable result, in view of "optimal maintenance planning": it corresponds on one side to the lowest preventive maintenance cost, and, on the other side, to the time interval between maintenance interventions capable to guarantee the required asset efficiency given limited financial resources. Implicitly, the time interval between each intervention is "expressed" through a monetary amount (as will be clarified in the next sub-section).

Thus, analogously to the Net Present Value hybrid formula expressed in Equation (11), by interpreting the Equivalent Annual Cost in a social-environmental-economic view, the following Equation can be obtained:

Figure 2. Annuity cost calculation – schematic example (Source: Author's elaboration based on CEN 15459:2007 – Energy performance of buildings – Economic evaluation procedure for energy systems in buildings, Final Draft, p.17).



$$AC_{soue} = C_{r\,soue} + \sum_i (a(i).\sum_j V_{0\,soue}(j)) + \alpha(\tau\_Building).(\sum_j V_{0\,soue}(j)) \tag{13}$$

where AC_{soue} is the Annuity Cost including costs/benefits for society, owner, user, environment, C_{rsoue} is the annual running cost (energy, operation, maintenance, etc., including society, owner, user, environmental costs/benefits) yearly distributed, $\Sigma(a(i) * (\Sigma V_{0soue}(j))$ is the total annualized cost/benefit related to j components/systems replacement, when the service life is lower than the building life cycle, $a(\tau\_Building) * (\Sigma V_{0soue}(j))$ is the total annualized cost/benefit related to j components/systems replacement, when the service life is unchanged during the building life cycle, being the life cycle longer than the building's one, $\Sigma(a(i)$ is the annuity factor when the component service life is lower than the building life cycle, $a(\tau\_Building)$ is the annuity factor when the component service life is longer than the building service life.

As argued in a recent study (Fregonara and Ferrando, 2020), the Annuity Method is suitable for testing maintenance interventions sustainability: in that case, two alternative building components are compared, assuming the perspective of the owner and a middle-term evaluation lifespan. All the more so in the case of the infrastructures, assuming a multiple perspective – owner, user, society, environment –, making reference to public works, and dealing with long-term lifespan projects.

Even if the Net Present Value and the Equivalent Annual Cost can solve equally the evaluation exercise, the Equivalent Annual Cost is preferable when the budget is defined on annual basis (according to the owner viewpoint), and, we can argue, even in long-term preventive cost planning. Furthermore, annualized amounts can better support the decision making process specifically when comparing different options, by giving less relevance to the total cost amounts of each alternative. For these reasons, and above all for the possibility to include also user/society/environmental costs into the model, it is worth exploring the effective applicability of (13).

4.2 Service life estimate, maintenance time intervals and durability

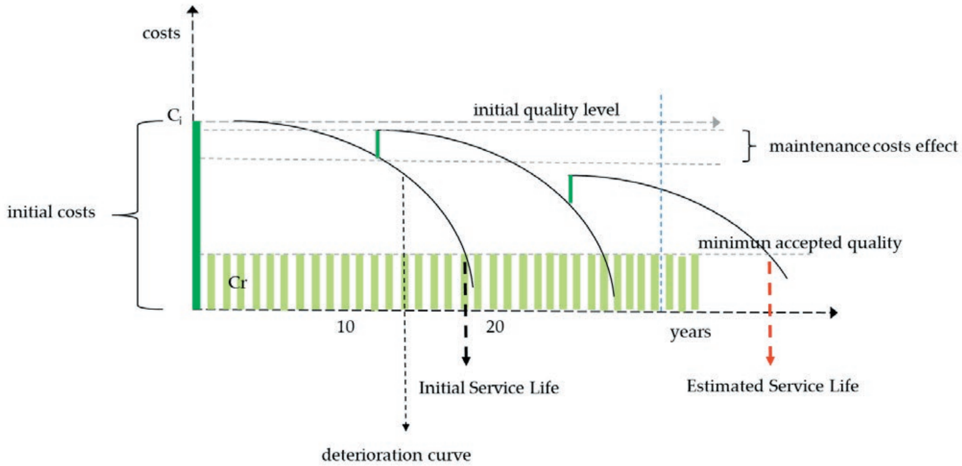
The operative modality presented in this section and formalized in (11) is suggestable for calibrating infrastructure optimal maintenance strategies. Nevertheless, the service life estimate represents a delicate step for the applicability of the approach. In fact, service life estimation implies the definition of maintenance time intervals capable to guarantee the maximum durability of the product, at the lowest investment on management costs. Durability in turn is a function of investments in maintenance and management activities.

This issue is faced in recent studies by exploring LCCA as a tool to support maintenance costs planning in the construction sector capable to guarantee the durability of a building/component/system/infrastructure given an acceptable quality level. The service life estimation is explored under different views, and, in general, deterministic or probabilistic approaches are used for modelling uncertain economic lives into the models application. Among the studies produced in the estimative-evaluative context, for example, researches propose the "engineering approach" through the stochastic approach to Factor Method, in order to estimate the service lives according to the probabilistic approach (Aarseth and Hovde, 1999; Fregonara and Ferrando, 2018; Galbusera et al., 2014; Gaspar and de Brito, 2008; Hovde and Moser, 2004; Moser and Edvardsen, 2002; Silva et al., 2016).

Many other studies produced in the civil engineering context are based on the analysis of the effects of maintenance interventions on construction performance, with the support of specific tools as, for example, the deterioration analyses. The reasoning capable to join the technological dimension to the economic one is fundamental for the present study, as for the generality of researches that streams from the concept of service life. In the schematic example in Figure 3, a simple performance curve is presented. Given an initial investment cost able to guarantee the higher quality level, to which corresponds an initial service life, for improving the quality level after the deterioration of the component, a maintenance investment is necessary. With each maintenance intervention the quality level increases, but less than proportionally, as far as the minimum acceptable quality level is reached. Obviously, the equilibrium between maintenance investments and improvements in quality level over time is variable. The aim is to identify the optimal point, which corresponds to the maximum service life at the lowest cost.

Thus, the "optimal maintenance planning" in function of life cycle costs and in presence of financial constraints is a second research address to be explored according to an economic viewpoint at the infrastructure scale.

Figure 3. Preventive maintenance cost effects: improvement of quality level and component durability. Schematic example.



4.3 Uncertainty in life cycle approaches

As mentioned before, the input data in the Equations presented in the study should be considered as expected values. In fact, uncertainty for example in deterioration processes as well as uncertainty in the market due to the variability in prices and demand dynamics, is capable to generate relevant consequences in maintenance costs/benefits prediction and in infrastructure projects/interventions/maintenance strategies. As recommended in literature, the uncertainty and risk should be controlled by introducing flexibility into the model, both in model input estimates, and in model output calculation. Among the studies, a first group aims at modelling the uncertainty in LCCA application through deterministic approaches. Despite the simplicity, the results of the analyses are limited. A step forward is represented by the probabilistic approaches to the LCCA as proposed in recent or relatively recent works (Arja et al., 2009; Boussabaine and Kirkham, 2004; Flanagan et al., 1987; Fregonara et al., 2018), some of which referred to the infrastructure sector (Del Giudice et al., 2014; Frangopol, 2011; Menendez and Gharaibeh, 2017; Padget et al., 2010; Scope et al., 2016; Sun and Carmichael, 2018). Thus, the stochastic Global Cost and the stochastic Annuity Method can be formalized, by modelling input data as stochastic variables and by solving the models through the Probability Analysis and the Monte Carlo Method.

The shift from the deterministic approach to LCCBA to the probabilistic one represents a third address for implementing the research.

5. Conclusions

In this article a methodology for supporting the maintenance investments planning in function of life cycle costs and benefits was presented, assuming the presence of uncertainty over time and focusing on the use-maintenance-adaptation stage in the infrastructures' life cycle. An operative modality was proposed for ranking the economic sustainability of alternative project options, which implies different cost/benefit amounts for maintenance-replacement interventions over time.

Assuming the Circular Economy principles, the work tried to implement the evaluation of potential impacts on production and consumption processes, specifically in terms of costs and benefits impacting on consumers and producers behaviours. The objective was to ensure sustainable dynamics in the public/private construction processes, since the early design stages till the end-of-life stage and focusing on the use-maintenance-adaptation phase. Implicitly, it was assumed that new concepts of economic development are deriving from the awareness of environmental issues, for protecting natural systems: among these, the Circular Economy concept involving different activities: raw materials extraction, use-maintenance-adaptation, final disposal, reuse or recycle. By tracing back the Circular Economy concept to the theoretical approach of Life Cycle Thinking, and thus considering the project as a process which develops along its whole life cycle, at the different scales and from the single technological component to the whole building, the Life Cycle Costing Approach in conjunction with Cost Benefit Analysis was explored.

Considering that the paper intended to be a methodological reflection and that the proposed modality must be supported by empirical evidence and applications, some potentialities and limits emerge. Among the potential advantages, the modality can be capable to support decision-making between alternative technological scenarios in public projects including impacts on society, users and environment, overcoming the LCC analysis and other consolidated approaches for which the owner viewpoint prevails. Moreover, in the case of infrastructures, the operative modality could be less time-expensive than the traditional CBA approach, and more suitable for treating the technological-economic components beside the social ones in the project evaluation. Nevertheless, a limit is represented by the input data detection as in the generality of the economic evaluation models. As the CBA, it requires the recourse to methods capable to quantify, when possible, externalities and social effects associated directly/indirectly with the interventions. Then, the concrete application of the approach requires the integration with competences from other disciplines (structural engineering, materials science and technology, environmental technology, etc.). Finally, three research directions are still to be explored: the applicability of the Annuity Method as an alternative to the Global Cost one, durability and the life cycle estimate, the probabilistic approach to solve the proposed methods by modelling uncertainty over time.

Summing up, the potentialities and limits of the methodology suggest its application for the socio-economic sustainability of public projects in decision-making contexts that involve the management and maintenance of existing infrastructures/assets, in presence of consistent technical-operational information. More specifically, the potentialities can be valorised (and the limits overcome) when in synergy with Facility Management competences, able to integrate the management of services and processes oriented to constructions, maintenance activities and technical-operational approaches, for supporting in the meanwhile spaces and communities involved in the decisions.

This last consideration highlights, in a certain way, the application domain of the proposed operational steps.

Above all, given the methodological nature of the present study, and given the aim of sharing the knowledge with the scientific community, the application on a concrete case-study is demanded to a future research.

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Opportunity-spaces for self-regenerative processes: assessing the intrinsic value of complex peri-urban systems

The research aims at evaluating the ability of a peri-urban system to activate territorial self-regenerative processes, according to Circular Economy principles. The adopted methodology identifies *opportunity-spaces*, through indices of space heterogeneity and of the relational dynamics, established in collective spaces. Through a site-specific set of indicators, it evaluates opportunity-spaces intrinsic value, adopting Analytic Network Process (ANP) as Multi-Criteria Decision Aid method (MCDA). As a result, five categories of opportunity-spaces are defined and spatialised, within hill area of Naples, in the South of Italy.

1. Introduction

1.1 Theoretical background

Urban critical issues, related to territorial marginality and exclusion, often emerge within those in-between metropolitan areas, which can be referred to as *peri-urban spaces* (Brook and Davila, 2000; Iaquinta and Drescher, 2000; Allen, 2003; Marshall et al., 2009). These are conflicting and heterogeneous areas, made of a differential and fragmented reality, where intermediate and ambiguous zones are continuously being generated (Lefebvre, 1974). They are places of social and spatial negotiation, where polarities meet, keeping the urban relational dynamics alive (Stavrides, 2016). According to this perspective, the contribution investigates the possibility for these urban areas to activate complex dynamics, functioning as a territorial *residue* (Clément, 2004), where the urban metabolism (Wolman, 1965) is to be understood through an interdisciplinary perspective, combining natural and social sciences (Dijst et al., 2018) and interpreting cities as ecosystems, produced by different complex processes, which can develop into self-sufficient ones, if conceived according to an *autopoietic* thinking (Varela et al., 1974), deriving from the study of ecosystems mechanisms.

The Circular Economy (CE) concept, referring to natural ecosystems intrinsic capacities, as well, conceptualises the definition of urban metabolism within a wider framework of *urban circularity* (Marin and De Meulder, 2018), a model pro-

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moting the development of environmental, social and economic innovations, allowing urban self-regenerative processes. An interesting parallel can be traced between the elements of a CE cycle, happening in the city, and the territories deriving from urbanisation processes: indeed, CE proposes to introduce what is *residual* of a consumption chain into sustainable loop processes of reuse and renewability, for value creation, turning wastes into services (Ceschin, 2013; EMF, 2013). Berger's (2006) concept of *wasted places* refers to marginal and abandoned sites and is strongly related to Clément's (2004) definition of *residual landscape* as *third landscape*, which is connected to uncultivated areas, fragments of uncertain landscape, in a dynamic state of waiting, where hybrid and entropic spaces, being always in motion and transformation, can be understood as the complex product of a *social vitality* (Clément, 2006, p.128).

According to this interpretation, the research analyses the case-study periurban area as a complex territorial system, where the circularity strategy and the renewable closed-loop processes, at the base of CE (Stahel, 1982), could turn the concepts of residual and waste places into their understanding as vital areas: in recent times, for example, the CE strategies are being applied within urban critical, hybrid and underutilised areas (Lewin and Goodman, 2013; EEA, 2015; Hassan and Lee, 2015). In this sense, the paper refers to the widening of the concept of circularity towards the definition of its urban dimension (Marin and De Meulder, 2018), aiming at addressing urban circular processes as spatial practice (Prendeville et al., 2017).

The definition of cities as complex systems is shifted from the biological world. Biology defines the ecosystem as a natural system, made of biotic and abiotic factors, which synergistically interact, constituting the ecosystem self-sufficiency and dynamic balance. Social ecology, stressing social and urban systems ability to manifest social diversity, mutualism and connectivity, considers them as ecosystems, as well – also defines them as *eco-communities* – underlining their self-producing mechanisms (Boockchin, 1992). At the same time, urban ecology, considering the city as a living organism, studies the biodiversity of urban systems, as deriving from the synergistic coexistence of social ecosystems and natural ecosystems (Müller et al., 2013): an urban ecosystem is the product of the interaction among natural capital, manufactured capital and cultural identity of places (Magnaghi, 2010). An urban hybrid territory is, therefore, substantiated as a spatial ecosystem, composed of different complex subsystems, allowing the vital (environmental-economic-social) conditions for the system itself, hence its self-development: the marginal urban landscape provides the city with ecological, material and energy resources and works as environmental support (Haines-Young and Potschin, 2018), constituting the self-regulating and balancing capacities of the metropolitan system between the natural ecosystem sphere and the anthropic pressures that tend to modify it (Maes et al., 2018); creative enterprises, clusters of creative industries (Zheng and Chan, 2014), social enterprises and cooperatives are giving way to alternative economies (Boonstra, Boelens, 2011), based on collaborative and supportive community mechanisms; cooperative actions produce the territory itself, by aiming at self-governing it, through self-organising processes (Magnaghi, 2015).

Combining these different subsystems, the metropolitan heterogeneous territory synergistically links natural ecosystems and urban ecosystems (natural capital and manufactured capital), whose vitality depends on the capacity of a community (social capital and human capital) to be in solidarity, guaranteeing: integration and coevolution; the possibility to build a collective identity-based sense of recognition in a place or in a culture over time; the activation of cooperative and self-organising processes.

In ecology, self-producing ecosystems are defined as *autopoietic* and are organised through a network structure of mutual interactions among the elements that make up the system (Varela et al., 1974). A first attempt to abstract the concept of autopoiesis from the biological world theorises a trans-disciplinary concept, according to which not only living systems, but also physical systems and social systems can be defined as autopoietic (Luhmann, 1986; Seidl, 1992). Ecosystems can be considered as the realisation of the autopoietic organisation, as they produce themselves: if an ecosystem is autopoietic, it is necessarily a *social* system (the opposite is not necessarily true); a spontaneous social system (not defined by heteropoietic mechanisms, external to the system) that produces itself is *autopoietic* (Zeleny and Hufford, 1992; Zeleny, 2009). Autopoietic social systems have been studied through categories, which differ on the type of communication (reciprocal interactions in the social system), that links the system parts to each other (Luhmann, 1986; Schatten, Bača, 2010). The communication mechanism of autopoietic systems is at the base of their *structure* and *organisation*: the first one refers to the system composition, to the types of elements and interactions among the elements; the second one refers to the network of coordination rules among the system parts, which, within a social system, are the interactions among different personalities, their bonds and relationships, regulating people association (Zeleny and Hufford, 1992; Zeleny, 2009). Then, social interactions, allowing communication among the system parts, not only organise the system itself but, by transferring information, informatise it, retain and metabolise the information that makes the system able to compare the external environment and the changing needs of those who use it (Bača, 2007).

The first definition of an autopoietic social system, as a self-referential system – which defines itself distinguishing itself from the external environment (Luhmann, 1986), through a defined and closed perimeter (Varela et al. 1974; Zeleny, Hufford, 1992) – is reinterpreted through an information system model, reacting to environmental impulses and continuously adapting to them (Quick, 2003): this type of ecosystem can be considered as a complex adaptive system (Gunderson and Holling, 2002), whose development is linked to a limited degree of predictability (Costanza et al., 1997, p. 103). Therefore, an autopoietic ecosystem reproduces itself, through a structure and an organisation, based on the information transfer, through relationships and links; it is then social; the information transfer makes the system adaptable to the external environment, therefore resilient.

The notion of autopoiesis of ecosystems is linked to that of *land health*, defined by Leopold (1949) as the capacity of the land for self-renewal (Walck and Strong, 2001). Leopold evaluated it through the criteria of *integrity*, *stability*, *productivity* and *beauty* of the biotic community (Leopold, 1970; Walck and Strong, 2001): *integrity* represents the set of elements of the system/community, linked by interdependence relations (this definition can be easily associated with that of the ecosystem); *stability* (far from the concept of stasis) refers to the organisation through which the system/community develops; *productivity* is the capacity of the system/community to produce what it needs for its survival (this concept could be associated with that of self-support); *beauty* is connected to the system/community intrinsic value, which consists in the capacity for self-renewal.

Costanza (1992) associates the definition of *ecosystem health* to the concepts of *diversity or complexity*, and formulated three indicators, through which the ecosystem health and integrity can be evaluated: *stability or resilience* can be defined as the ability of the ecosystem to absorb external pressures and adapt to them creatively, rather than resisting to them, by maintaining its unchanged configuration; *vigor or scope for growth* refers to the ecosystem productivity, activity or metabolism; *balance* among the components of the ecosystem. This concept is synthetized by the expression $HI=VOR$, where: HI is the complex ecosystem health index and a measure of sustainability; V, the vigor; O, the ecosystem organisation; R, the resilience. The ecosystems capacity for self-renewal, or self-production – autopoiesis – constitutes the *ecosystem intrinsic value*, *EIV* (Zhang et al., 2015).

If the concept of intrinsic value is linked to that of system complexity, studying a complex territorial system implies the need to analyse its capacity to produce intrinsic value. Assuming an autopoietic and ecosystem approach, based on the definition of natural ecosystem integrity and health, the formation process of intrinsic values can be analysed within social and urban ecosystems as well (Fusco Girard and Nijkamp, 1997). Cerreta and De Toro (2001) propose the index $I=ORV$ to evaluate the integrity of urban systems and their capacity to self-organise over time, shifting the terms used by Costanza from the natural sphere to the social and anthropic one. In this expression, the terms *resilience* and *organisation* are related to that of *vitality*, that is to be understood as the capacity of the urban system to enable the social self-production of material and immaterial relationships, of common feeling and shared place identity, to produce that *primary value*, on which the formation process of the other values depend, the *intrinsic value*, *IV* (Pearce and Turner, 1990; Fusco Girard and Nijkamp, 1997). Turner (1992) defines this value as *glue value*, since it keeps different individualities of a community together, tying them within a structure. IV cannot be evaluated in monetary terms since it depends on social vitality and social capital: it is, also, referred to as *intangible* (Daniel at al., 2012) and *incommensurable* (D'Agostino, 2000). Non-monetary values can refer to: *cultural/historical values*, based on cultural heritage, and held by a distinguishable society and its institutions (Frey, 1994); *social* or *societal values*, based on civic engagement in decision-making, cultural and recreational shared activities, participation and inclusion (Dirksmeier, 2008; Pike at al., 2011; Sherrouse et al., 2011); *communal values*, shared by a local community, and based on place-based identity, spiritual connection to a land or place, symbolic and iconic identification (Gobster, P.H., 2001; Kato, 2006; Kanowski and Williams, 2009; Cerreta and Panaro, 2017). A community is realised within the physical space of a city, that supports its activity, its culture, the formation of social relationships and shared habits. Such a city can be defined as biopolitical (Hardt and Negri, 2011), being structured through a living dynamic of cultural practices, intellectual circuits, affective networks, and social institutions (Hardt and Negri, 2011, p. 154). In essence, it allows urban vitality formation, by strengthening the social productive power. This dynamic constitutes the immaterial drivers (Goonetilleke et al., 2011) catalysing the metabolic capacity of the city to activate urban regeneration processes, based on the local culture (Sacco et al. 2014) and the creative capacities of an urban community.

1.2 Research questions and aims

This research investigates a heterogeneous peri-urban system in Naples, in the South of Italy, identifying the *opportunities* deriving from the relational dynamics in collective spaces. The case study is selected, though a preliminary analysis of the city peri-urban spaces, according to which the two main spatial categories, studied in this research, heterogeneity and relational consistency, result to be considered as very much specific for the study area. The methodology aims at detecting the capacity of this territory to allow the catalysation of urban regeneration processes, based on self-production, self-organisation and place identity enhancement, through the development of a place-based model. This derives from the analysis and interpretation of uses and relationships in collective space and highlights how use and non-use values and the opportunities of a marginal urban area can depend on IV. According to an autopoietic thinking, based on the attempt to activate local cooperative processes, this study evaluates the IV of the analysed spatial-social system, through criteria of *organisation (cooperation), resilience* and *vitality*.

The contribution engages with the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2015), deepening, in particular, the issues related to social self-development and inclusive urban spaces promotion, defining site-specific quantitative and qualitative indicators. These differently refer to the categories mentioned above and to types of possible local regeneration processes and social synergies among the inhabitants-stakeholders, that could enable the definition of a local social ecosystem.

The following questions address the methodological approach: How can opportunities, deriving from the use of space and the relational dynamics in collective spaces, be identified and spatialised? Can synergistic territorial processes be addressed, according to the different identified opportunities, and starting from the evaluation of social self-production capacity and IV?

In order to answer to the above issues, in Section 2 the methodological framework is described; in Section 3 the application to the selected case-study is presented; in Section 4 the results are analysed, and in Section 5 the discussion and conclusions are presented.

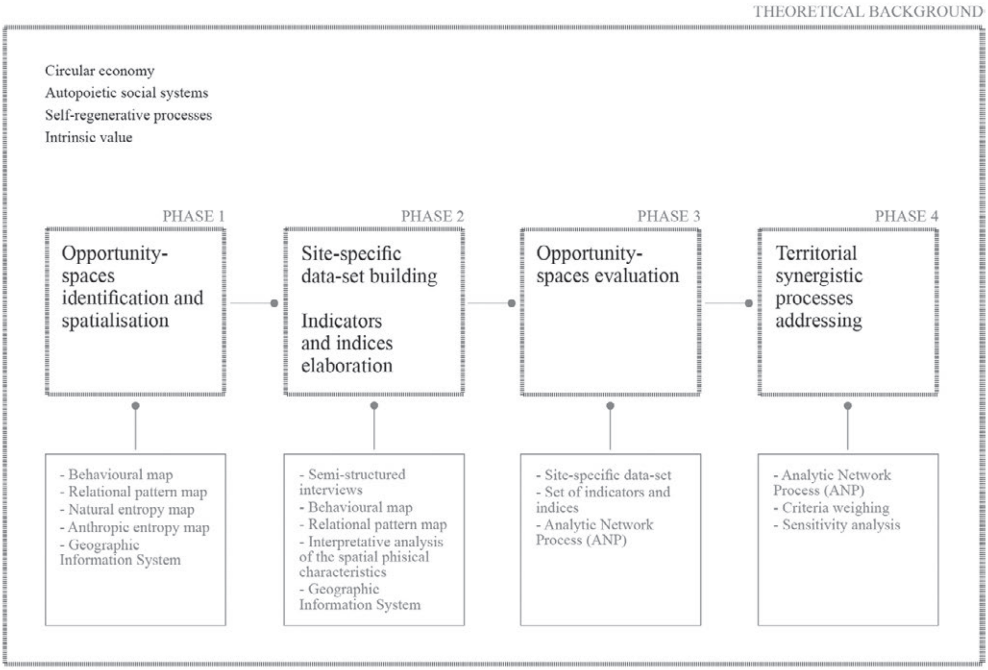
2. Materials and methods

Adopting an ecosystem approach to social systems analysis, the proposed methodology develops an evaluation framework, integrating different data elaboration methods, to catch the different dimensions of values, and, in particular, the immaterial one of the IV.

The methodological structure can be summarised through the following phases (Figure 1):

1. Identifying and spatialising opportunity-spaces, according to the use of space and to the relational dynamics in collective spaces (*2.1*; *4.1*);
2. Building a specific set of quantitative and qualitative indicators, defining the different characteristics and potentials related to each type of opportunity-space (*2.2*; *4.2*);
3. Evaluating the opportunity-spaces, through the categories of organisation, resilience and vitality, and the criteria, specifically defined for the case study, in order to understand the local dynamics depending on IV (*2.3*; *4.3*);
4. Addressing different synergistic processes, based on the identified opportunities (*2.4*; *4.4*).

Figure 1. The methodological framework for the opportunity-spaces evaluation.



2.1 Opportunity-spaces identification and spatialisation

Meaning by *opportunity* the possibility to start or catalyse a cooperative and synergistic process within a space, opportunity-spaces are identified according to the heterogeneous physical characteristics of a space, and to the relational dynamics detectable in this space. Four indices are structured, elaborating the data deriving from different interpretative analysis of the use of space and of people's activity and behaviour according to the use of space itself:

- Environmental entropy H_e;
- Anthropic entropy H_a;
- Complexity of relationships R_c;
- Density of relationships R_d.

These indices are measured through a spatial discretisation, corresponding to a 20x20 meters grid, that is the minimum spatial unit for the values to be assessed. This allows the spatialisation of the measured values within GIS software. For this contribution, *QGIS 3.4* software was used, implementing a GIS-based data-set, collecting the results of the interpretative analysis and the interviews. Below, the elaboration methods of the four indices are described.

The analysed area consists of a very hybrid and heterogeneous territory, with different – natural, rural and anthropic – fabrics and realities overlapping. The characteristic of *the disorder* is, here, considered as an indicator of the urban space metabolic capacity. Today, urban complex systems are interpreted through new categories, shifted from the biological world. Through the studies of landscape ecology (Vranken et al., 2015), the concept of *entropy* has emerged as an indicator of complexity in territorial systems: spatially, it can be interpreted as *heterogeneity*, complexity of the landscape pattern, according to the types of land occupation and their configuration (Fahrig at al., 2005); temporally, as *unpredictability*, instability in landscape evolution. The first one is an indicator of diversity concentration, combination and configuration; the second one of the landscape ability to be resilient, to respond to various types of external pressures, often caused by human activity (Zaccarelli et al., 2013; Zurlini et al., 2013). Shannon's entropy index (Shannon and Weaver, 1948) (Equation 1), having applications to many fields, is being used in territorial and landscape analysis as a measure of: marginal urban landscape complexity (Cerreta and Poli, 2013); urban growth dynamics (Cabral at al., 2013); spatial concentration of information and data (Batty at al., 2014); the built environment morphological structure (Boeing, 2018); informality in temporary spontaneous settlements (Lara-Hernandez et al., 2019).

$$H = -\sum_{i=1}^{n} pi \; ln\, pi \tag{1}$$

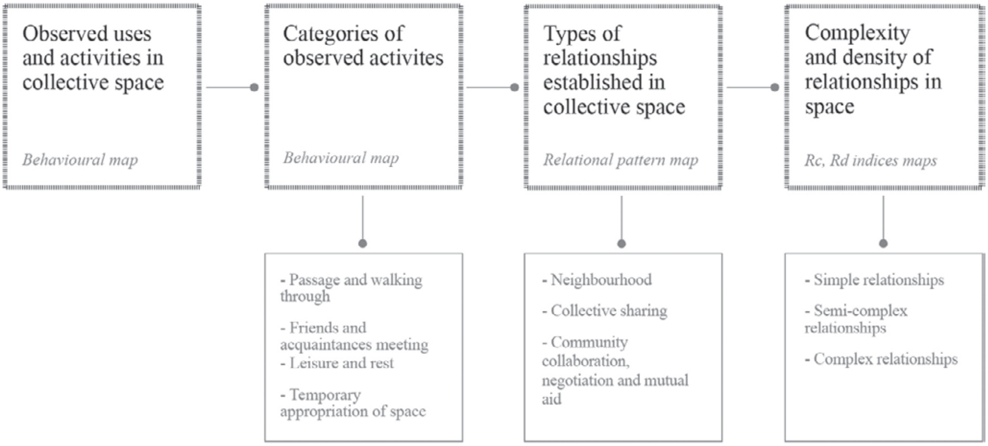
Where: i = considered features; n = number of different features; pi = frequency of the features within the considered area, that is, the probability of finding the features within the considered area, and it is calculated as a ratio between n and n_{max}. H varies from 0 to $ln\ n$. The higher its value, the greater the concentration of heterogeneity or disorder in the analysed space.

Here, two entropy indices are developed: one, expressing *environmental entropy* H_e, and measuring the types of different natural species; the other one, *anthropic entropy* H_a, measuring different characteristics of the built fabric. In particular, H_a takes into account: the presence of buildings, surrounding the analysed area; material alterations and anomalies of these buildings; informal structures; planned and unplanned street furniture; mobile objects of various types, insisting in collective space.

The other two indices derived from the attempt to detect the daily relational dynamics happening within collective space. The literature studying activity patterns in public space has developed the *behavioural mapping* methodology, to inquiry about spatial relations between occupancy and the physical structure of squares and parks in city centres (Goličnik, 2005). It registers the uses of spaces, through different repeated observations, on different days and time; it discusses the results, analysing the activity and behavioural patterns; it uses interactive GIS maps, building an empirical knowledge structure. The behavioural maps elaborated within this research were developed as it follows: observations were conducted on different days and time, over a period of one year; the points of observations were chosen according to the visibility of space; the different observed uses and activities were registered on-site while developing a legend of symbols corresponding the activities (Goličnik, 2005); photographic materials were also collected to support the description of the different activities; the results were then registered through GIS tool, according to the detected categories of uses. Three different maps resulted from this empirical process. The indices elaboration was conducted according to only one map, the one reporting the highest presence of people in space, to consider the highest observed level of spatial sociability. The observed activities were divided into four categories: passage and walking through; friends and acquaintances meeting; leisure and rest; temporary appropriation of space. Each category of activity has been related to a type of relationship, established by people in collective space - this step was possible, because of some short interviews made during the observations: to the first activity category, the relationships of *the neighbourhood*; to the second and the third ones, the relationships of *collective sharing*; to the fourth one, the relationships of *community collaboration*, *negotiation* and *mutual aid* (Figure 2). These types of relationships were classified as: *simple* (relationships of the *neighbourhood*), daily interactions, realised in collective spaces close to the private ones and involving a neighbourhood community; *semi-complex* (relationships of *collective sharing*), constituting potential bonds within a local community; *complex* (relationships of *community collaboration*, *negotiation* and *mutual aid*), generating community ties and common feeling (Figure 2). Through this empirical analysis, a spatial map of social relationships was defined, informing on *which types* of relationships have been realised *where*, and with *which level of frequency*. As a consequence, the two indices, measuring the relational consistency of space, were so defined: *complexity of relationships* R_c, according to the classification mentioned above; *density of relationships* R_d, according to the frequency of people in space, registered through the behavioural map (Figure 2).

According to the interpretative analysis, a first attempt to define the qualitative characteristics of the opportunity-spaces, through some categories, is made,

Figure 2. Behavioural map processing, relational consistency of space.



summarising the main features, that emerged within the different observed spaces, where the relational dynamics were mapped:

- *Relational* space, where the frequency in space, hence the relational density, are high, but these relationships are classified as *simple*;
- *Metabolic* space, where many heterogeneous dynamics seem to be happening in the hybrid space;
- *Residual* space, where the frequency in space is low, but the landscape quality and the presence of green spaces, enable people to establish spatial bonds;
- *Inclusive* space, where complex relationships pattern is very dynamic;
- *Natural-non-anthropised* area, where there is a strong presence of the natural ecosystem, and the frequency of people in space is very low.

In order to spatialise and evaluate them, these attributes are expressed through the *He*, *Ha*, R_c, R_d indices, associating to each type of opportunity-space four value ranges, corresponding to the assessed indices.

2.2 *Site-specific data-set building*

The data have been collected and produced according to four criteria of analysis: services and facilities; use of space and physical characteristics of space; people's behaviour according to the use of space; perception of space. The data production method was based, as already mentioned, on different types of integrated analysis: spatial interpretative analysis, according to the spatial physical characteristics and elements, and the use of space (Nijhuis et al., 2011; Lara-Hernandez et al., 2019); behavioural mapping and social-spatial relationships mapping (Goličnik, 2005; Müller-Eie et al., 2018); consultation with experts and actors; semi-structured interviews (Kallio et al., 2016). The latter were conducted at various levels of the methodological process: to link the activity pattern, detected in space, with the relational one; to integrate the data with information about the daily social habits and practices, happening in space; to measure the perception of space, inclusion and security, the shared sense of place belonging and identity.

The indicators and their domains, referring to the categories of organisation, resilience, vitality, and to the SDG's indicators, highlight the opportunity to activate local synergistic and cooperative processes, as well as the material and immaterial benefits, deriving from them.

2.3 Opportunity-spaces evaluation

The research adopts the Analytic Network Process (ANP) (Saaty, 2006) multicriteria method for the opportunity-spaces evaluation. The ANP is a Multi-Criteria Decision Aid method (MCDA) that overcomes the Analytic Hierarchy Process (AHP) hierarchical structure, allowing the decision problem to be structured through a network model, based on interactions and dependencies among elements, belonging to different hierarchical levels. These are interrelated clusters and nodes, contained within the clusters. ANP method develops a supermatrix, in which the priorities – established through pairwise comparisons, as well as in the AHP method – are integrated. The supermatrix expresses the influence of an element on another one, according to the selected criteria, hence the dependencies among the clusters and the nodes of the network. The ANP, has, indeed, been selected as MCDA method, because it is suitable to represent the decision problem characterised by many interrelations among the chosen criteria and indicators, selected in the evaluation process.

The ANP is able to capture different aspects of "tacit knowledge", and the different elements are grouped into clusters of related factors, and links are made from a parent factor in a cluster to several elements, for example, the alternatives of the decision in another cluster. They may influence the parent or be influenced by the parent with pairwise comparisons being made to establish their priorities. A network is comprised of the clusters, elements and links. According to Saaty (2006) the ANP is based on a descriptive theory that combines these measures to match what people actually do or guides them to do better than they were previously using only qualitative thinking and hunches, and not limited to the top-down thinking of the hierarchic models. A simple network can be extended to complex multi-level models of networks of benefits, opportunities, costs and risks. The software used in this research for the ANP evaluation is *SuperDecisions 3.2*.

2.4 Territorial synergistic processes addressing

In the ANP model of this research, the opportunity-spaces are considered as alternatives; the different processes, that could be activated according to the chosen criteria, are interpreted as clusters; and the indicators as nodes. However, the aim of this evaluation – instead of choosing among alternatives – is to define which type of synergistic process could be better activated within which type of opportunity-space, that is to recognise the territory aspirations and intrinsic features, enhancing them. This result is obtained by progressively attributing different priorities to the clusters and repeating the ranking elaboration for each priority.

When the distinction among some of the opportunity-spaces results to be not very definite, a sensitivity analysis is conducted. Sensitivity analysis allows balancing the uncertainties related to the evaluation output, according to the needs and interests of the actors involved in the decision process. The result can be very much affected by the different sources of involved interests.

3. The case study

3.1 Peri-urban space in Naples

The analysed area is a peri-urban region, located in-between the central urban districts of Naples (Italy) and the inland municipalities, surrounding the city. It is part of Piscinola district, being connected to the historical city centre and the districts on the northern hills through an urban tube line. The study area is very close to the northern part of Capodimonte park – one of the biggest urban park in Naples – and can be located between the limits of the districts of Colli Aminei and Scampia; it is largely included in the Regional Park of the Hills of Naples (Città Metropolitana di Napoli, 2004), being crossed from south-west to north by the northern part of San Rocco valley, a yellow tuff gorge, occupied by large wooded areas (Figure 3). In the 2004 Report of Naples General Master Plan (Comune di Napoli, 2004), the area description underlines the predominantly agricultural use of the territory and the heterogeneous composition of the urban fabric: illegal and

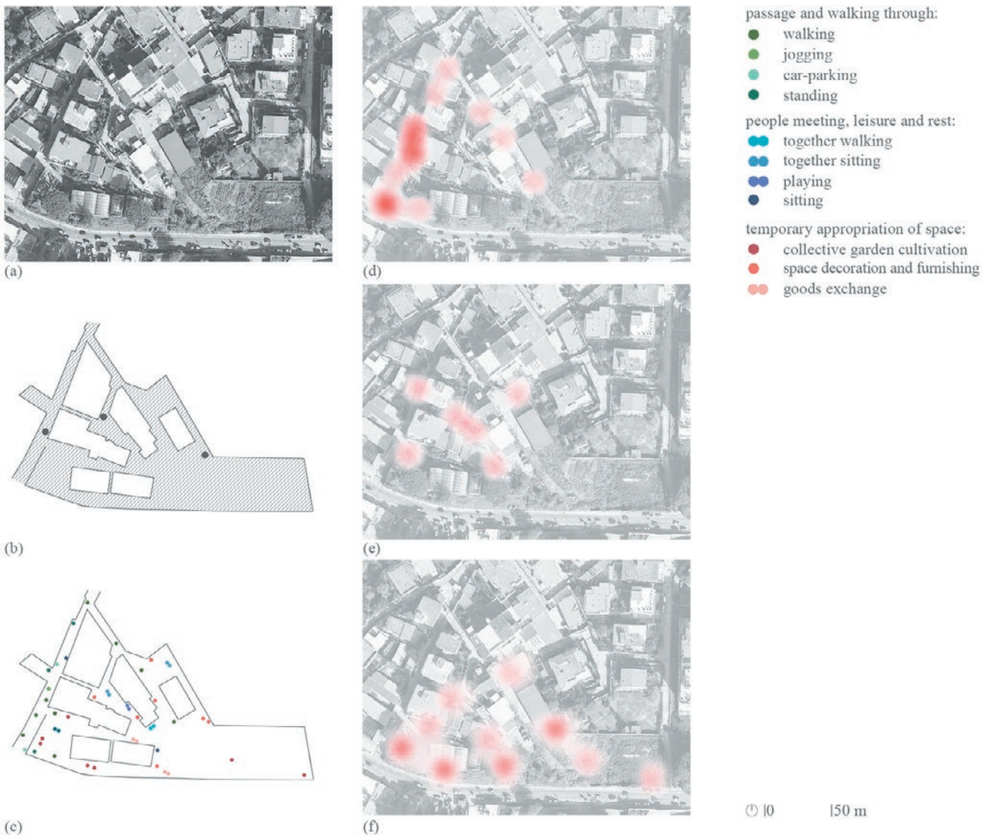
Figure 3. (a) Campania region, Italy; (b) Municipality of Naples, Metropolitan City of Naples; (c) study area, Municipality of Naples; (d) study area, built fabric and urban green areas.

non-normed buildings – constituting an actual new urban fabric – overlap with the cultivated areas, where the presence of farmhouses and rural buildings persists; peri-urban agriculture coexists seamlessly with the urban fragments of ancient and recent formations. San Rocco valley constitutes an extensive ecosystem resource for the city, crossing the urban built fabric and the rural areas. The uncultivated and unused green areas are widely distributed on this territory, resulting from different abandonment processes of rural and productive structures.

3.2 Behavioural mapping, social-spatial relationships

For the behavioural map elaboration, many observations were conducted on different days in ten months. Three of them resulted in being the most interesting, reporting the highest frequency in space: February 5th, 2018 – a Friday after-

Figure 4. (a) exemplificative focus area; (b) points of observation; (c) behavioural map; (d) heath-map for the category *passage and walking through*; (e) heath-map for the category *people meeting, leisure and rest*; (f) heath-map for the category *temporary appropriation of space.*



noon; May 1st, 2018 – a national holiday, celebrating workers' rights; November 17th, 2018 – a Saturday morning. The average observation time for each observation point lasted 30 minutes. In Figure 4, an exemplificative focus area – west of the study area – is shown, reporting the activity pattern registered on November 17th. Different observed uses and activities are represented according to the chosen categories of activities: *passage and walking through* refers to *simple* relationships; *people meeting, leisure and rest* to the *semi-complex* ones; *temporary appropriation of space* to the *complex* ones.

3.3 Spatialisation of He, Ha, R_c, R_d indices, with GIS support

In Figure 5, Environmental entropy (*He*), Anthropic entropy (*Ha*), Complexity of relationships (R_c), Density of relationships (R_d) indices are spatialised, according to the 20x20 meters grid. *Ha* values result higher where commercial and sports facilities are located, and, in particular, within informal and unplanned settlements. *He* values are quite high within agricultural areas and highest within San Rocco valley wooded area. The two indices of relational dynamics define the same areas, with different value intensity: within commercial areas, for example, R_d values result high. In contrast, R_c values are low, that is to say, that these areas are very frequented, but cannot be related to the realisation of spatial bonds among people, since the observed uses are connected to walking through activities. R_c and R_d are spatialised according to a 0-3 based scale, where: 0 stands for those areas in which the activity dynamics are very low; 1, for *simple* (R_c) and *less frequent* (R_d) relationships; 2, for *semi-complex* (R_c) and *frequent* (R_d) relationships; 3, for *complex* (R_c) and *very frequent* (R_d) relationships.

4. Results

4.1 Opportunity-spaces

Following the definitions of the opportunity-spaces (*2.1*), their attributes are expressed through the *He*, *Ha*, R_c, R_d indices, associating each type of opportunity-space to four value ranges, according to the four measured indices (Table 1). *He* varies from 0,00 to 2,00: three equal value ranges are chosen, representing low (0,00-0,67), intermediate (0,67-1,33) and high (1,33-2,00) values. *Ha* varies from 0,05 to 1,92: three equal value ranges are chosen, representing low (0,05-0,67), intermediate (0,67-1,30) and high (1,30-1,92) values. Opportunity-spaces are spatially identified, by matching the *He*, *Ha*, *Rc*, *Rd* values, measured within the 20x20 meters spatial unit grid (Figure 6).

Three clusters of opportunity-spaces result to be located at the three corners of the study area, surrounding the cultivated areas, at the centre of the area. *Natural-non-anthropised* area coincides with San Rocco valley area, crossing the study area, among the three opportunity-spaces clusters. *Relational* spaces are to be found

Figure 5. (a) *Anthropic entropy* H_a; (b) *Environmental entropy* H_e; (c) *Complexity of relationships* R_c; (d) *Density of relationships* R_d.

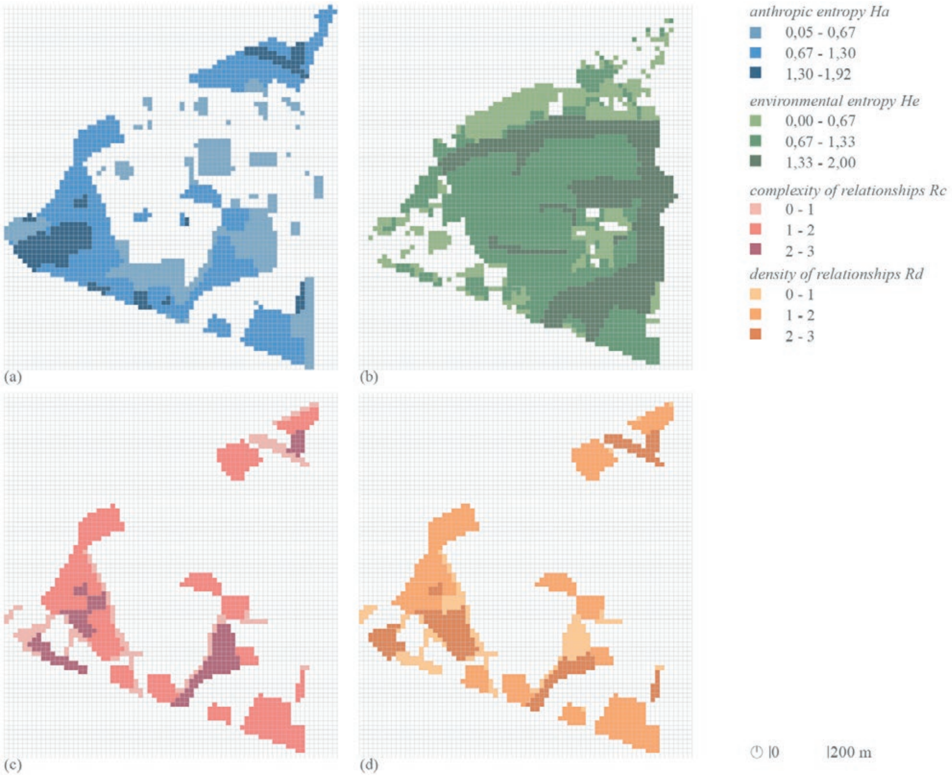


Table 1. Opportunity-spaces definition through value ranges of *He*, *Ha*, R_c, R_d indices.

	Relational	Metabolic	Residual	Inclusive	Natural-non-anthropised
He	0,00-0,67	0,67-1,33	0,67-1,33	0,00-0,67	1,33-2,00
Ha	0,67-1,92	0,67-1,30	0,67-1,30	1,30-1,92	0,05-0,67
Rc	1-2	2	3	3	0
Rd	3	2	1	3	0

near to the busy commercial streets or sports facilities. *Metabolic* spaces are very diffused and individuate those very hybrid areas, where the built fabric – often productive and storage buildings – and the rural one overlap, generating continuity zones among the mix-used areas. *Residual* spaces identify the various unused green areas, resulting from heterogeneous urbanisation processes: the inhabitants are now using these areas as collective gardens or unplanned parks, where to go

Figure 6. Opportunity-spaces spatialisation.

walking or jogging; they function as small green infrastructures within the urban fabric. *Inclusive* spaces are located in-between other zones, within more protected and inner areas, with indirect contact with the busy streets surrounding the study areas: these spaces include collective and shared semi-public-private threshold spaces among the housing buildings and the informal dwellings, shared courtyards and small neighbourhood streets.

4.2 Site-specific set of indicators

The selected set of 39 indicators and 13 domains is reported in Table 2. Each indicator refers to a specific SDG, while each domain to the categories of organisation, resilience and vitality, within the social-urban contexts. Quantitative and qualitative indicators values are reported in Appendix A, Table A1. With the exception for *Natural-non-anthropised area*s – being the area just a wide continuous one – indicators values are assessed within exemplificative opportunity-spaces, with a similar and comparable extension, for each type: in particular, the south-western identified spaces are considered. The relation among the domains, the possible synergistic processes and the different types of values is shown in Table 3.

Table 2. Site-specific set of indicators, for the opportunity-spaces evaluation.

Domain	Indicator	Indicator code	Data production method	Data source	Rel. to SDG's	Rel. to O-R-V
Local Attractiveness	Sights and landmarks	LA1	Spatial interpr. analysis	Authors' elaboration	11	Cultural and Economic Vitality
	Cultural facilities (cinemas, museums, theatres)	LA2	Open map consultation	OpenStreetMap	11	
	Commercial activities	LA3	Open map consultation	OpenStreetMap	8	
	Touristic facilities (hotels, b&b, renting rooms)	LA4	Open map consultation	OpenStreetMap	8	
Connectivity and Permeability	Public transport (near-by stops)	CP1	Open map consultation	OpenStreetMap	9	Urban Resilience
	Pedestrian paths, usable by people with disability	CP2	Open map consultation	OpenStreetMap	11	
	Cyclable paths	CP3	Open map consultation	OpenStreetMap	8	
	Parking lots	CP4	Open map consultation	OpenStreetMap	9	
Sociability	Density of relationships and people meeting in space	S1	Behavioural mapping	Authors' elaboration	11	Social Vitality
	Relational dynamics within the district	S2	Behavioural mapping	Authors' elaboration	11	
Common Green spaces	Accessible, non-fenced or privatized green spaces and parks	CG1	Open map consultation	OpenStreetMap	15	Urban Resilience
	Abandoned green areas of uncertain property	CG2	Spatial interpr. analysis	Authors' elaboration	15	
	Green spaces, used as community gardens	CG3	Spatial interpr. analysis	Authors' elaboration	15	
Negotiation	Informal spatial negotiation	N1	Semi-structured interviews	Authors' elaboration	11	Social Organisation and Cooperation
	Goods exchange	N2	Semi-structured interviews	Authors' elaboration	11	

Domain	Indicator	Indicator code	Data production method	Data source	Rel. to SDG's	Rel. to O-R-V
Mixed Use of space	Buildings uses and functions	MU1	Open map consultation	OpenStreetMap	11	Urban Resilience
	Public space uses and functions	MU2	Spatial interpr. analysis	Authors' elaboration	11	
Temporary Use of space	Daily/weekly uses and activity in public space	TU1	Behavioural mapping	Authors' elaboration	11	Urban Resilience
	Monthly uses and activity in space	TU2	Collection of news about public events	Websites of the Municipality and of the local associations	11	
Creativity	People's collective problem-solving capacity	C1	Semi-structured interviews	Authors' elaboration	11	Social Resilience
	Spontaneous actions and practices that could trigger new processes	C2	Semi-structured interviews	Authors' elaboration	11	
	Recycle and reuse processes	C3	Semi-structured interviews	Authors' elaboration	11	
Appropriation of Space	Public space occupied by people for daily practices	AS1	Semi-structured interviews	Authors' elaboration	11	Social Resilience
	Unplanned objects and furniture insisting on public space	AS2	Semi-structured interviews	Authors' elaboration	11	
	Threshold spaces of indoors-outdoors continuity	AS3	Semi-structured interviews	Authors' elaboration	11	
Communal Praxis and Networking	Neighbourhood informal initiatives and associations	CPN1	Semi-structured interviews	Authors' elaboration	11	Social Organisation and Cooperation
	Daily practices shared by people meeting in collective spaces	CPN2	Semi-structured interviews	Authors' elaboration	11	
	Complexity of relationships and bonds in space	CPN3	Semi-structured interviews	Authors' elaboration	11	

Domain	Indicator	Indicator code	Data production method	Data source	Rel. to SDG's	Rel. to O-R-V
Inclusion and Participation	Openness to externalities by a consolidated community	IP1	Semi-structured interviews	Authors' elaboration	11	Social Organisation and Cooperation
	Self-organized maintenance and cleaning of shared space	IP2	Semi-structured interviews	Authors' elaboration	11	
	People's involvement and interest in shared space defining	IP3	Semi-structured interviews	Authors' elaboration	11	
Place Identity	Space distinguishability and peculiar characteristics	PI1	Semi-structured interviews	Authors' elaboration	11	Social Vitality
	Sense of belonging to a neighbourhood/district	PI2	Semi-structured interviews	Authors' elaboration	11	
	Social habits derived from the specific local anthropisation	PI3	Semi-structured interviews	Authors' elaboration	11	
	Sense of security in public space	PI4	Semi-structured interviews	Authors' elaboration	11	
Urban Ecosystem	Wooded non-anhropised areas	UE1	Open map consultation	OpenStreetMap	15	Ecosystem Resilience
	Typical natural species	UE2	Local botanical expert consultation	OpenStreetMap	15	

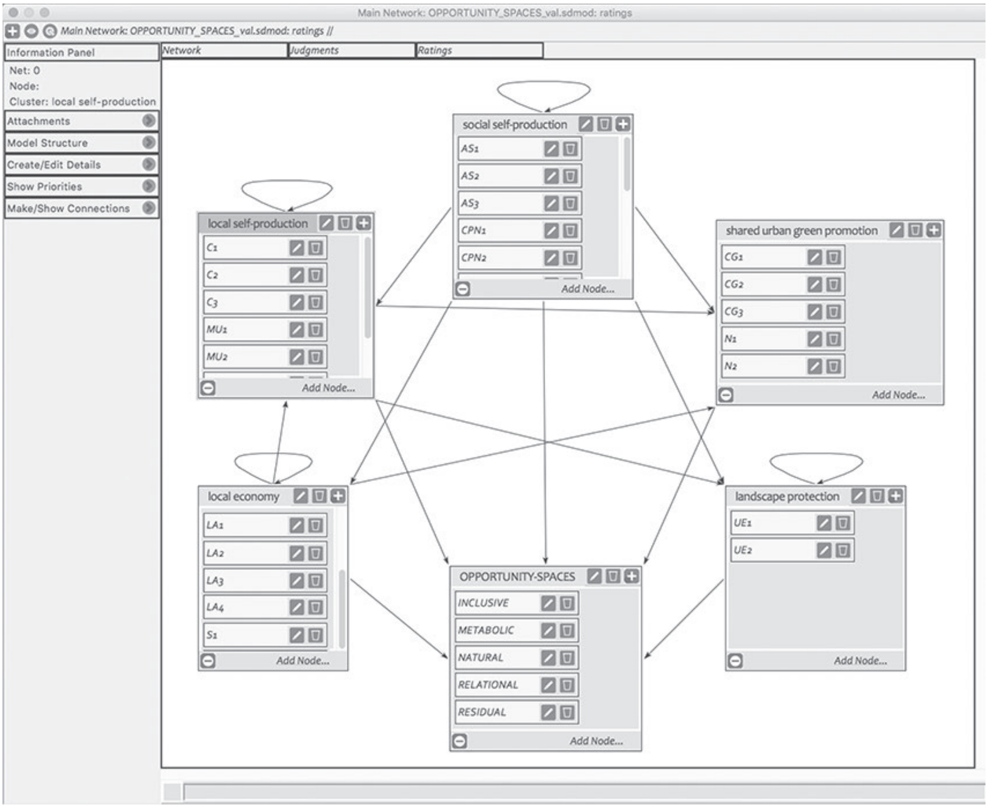
Table 3. Indicators domains, synergistic processes, benefits and values.

Process	Synergies	Benefit	Value	Domain
Local economy	Local enterprises and local administration	Local profits	Use value	Local Attractiveness
				Connectivity and Permeability
				Sociability
Shared urban green promotion	Cooperatives of inhabitants and local administration	Exchange of local products and social benefits	Use value and Intrinsic value	Common Green spaces
				Negotiation
Local self-production	Cooperatives of inhabitants	Exchange of local products and resources	Use value	Mixed Use of space
				Temporary Use of space
				Creativity
Social self-production	Open community of inhabitants	Mutual support and collective identity	Intrinsic value	Appropriation of Space
				Communal Praxis and Networking
				Inclusion and Participation
				Place Identity
Landscape enhancement and protection	Local associations and local administration	Ecosystem services	Non-use value	Urban Ecosystem

4.3 Opportunity-spaces evaluation with ANP method

The ANP network model is structured through 6 clusters (5 processes + 1 cluster for the opportunity-spaces) e 39 nodes, corresponding to the indicators. Connections and dependencies are established among elements of different clusters – network arrows – and of the same cluster – network loop arrows (Figure 7). The influence matrix shows these different dependencies among the elements (Figure 8). The opportunity spaces ratings, deriving from the overall ranking, result to be very similar, with the exception for the *Natural-non-anthropised area*, where – as it was, already evident, from the selected indicators and evaluation inputs – the only possible processes should be addressed towards the protection

Figure 7. ANP network model, screenshot from *SuperDecisions* software.



and maintenance of its integrity. The differences among the opportunity-spaces will emerge in the next phase, by attributing different priorities to the clusters.

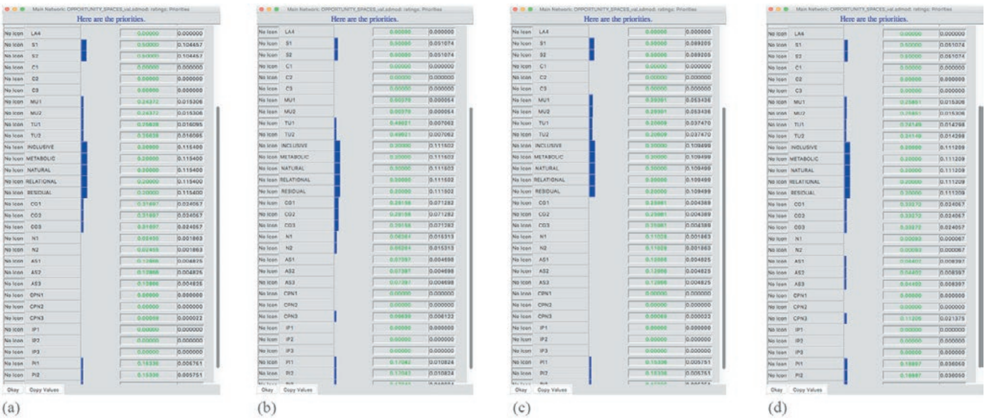
4.4 Opportunities and processes

By progressively attributing different priorities to the clusters (Figure 9), each opportunity-space is related to the process that better responds to its features and relational dynamics. In particular: the *Natural-non-anthropised* area is connected to the mechanism of landscape protection and enhancement; *Relational* spaces result to better catalyse public and private initiatives of local economic development; within *Metabolic* spaces, cooperative processes of local production could be activated; *Inclusive* spaces are to be considered as a spatial realisation of those immaterial and intangible processes of social self-production; *Residual* spaces could be linked to cooperative processes, related to sharing mechanisms, as well. As regards the possibility to promote the collective sharing of urban green areas, all four spaces – *Relational, Metabolic, Inclusive, Residual* – seem to respond very well, having very

Figure 8. Influence matrix, derived from the ANP method application.

		Opportunity spaces					Local economy										Shared urban green promotion					Local self production							Social self production													Land. enh.	
		Rel.	Mrt.	Res.	Incl.	Nat.	LA1	LA2	LA3	LA4	CP1	CP2	CP3	CP4	S1	S2	CG1	CG2	CG3	N1	N2	MU1	MU2	TU1	TU2	C1	C2	C3	AS1	AS2	AS3	CPN1	CPN2	CPN3	IP1	IP2	IP3	PI1	PI2	PI3	PI4	UE1	UE2
Opportunity spaces	Rel.						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Mrt.						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Res.						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Incl.						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Nat.						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Local economy	LA1	x	x	x	x	x																																					
	LA2	x	x	x	x	x									x	x																											
	LA3	x	x	x	x	x									x	x																											
	LA4	x	x	x	x	x									x	x																											
	CP1	x	x	x	x	x									x	x	x	x	x			x	x																				
	CP2	x	x	x	x	x									x	x	x	x	x			x	x																				
	CP3	x	x	x	x	x									x	x	x	x	x			x	x																				
	CP4	x	x	x	x	x																																					
	S1	x	x	x	x	x																																					
	S2	x	x	x	x	x																																					
Shared urban green promotion	CG1	x	x	x	x	x																																					
	CG2	x	x	x	x	x																																					
	CG3	x	x	x	x	x																																					
	N1	x	x	x	x	x																																					
	N2	x	x	x	x	x																																					
Local self production	MU1	x	x	x	x	x																																					
	MU2	x	x	x	x	x																																					
	TU1	x	x	x	x	x																																					
	TU2	x	x	x	x	x																																					
	C1	x	x	x	x	x											x	x	x					x	x																		
	C2	x	x	x	x	x											x	x	x					x	x																		
	C3	x	x	x	x	x											x	x	x																							x	
Social self-production	AS1	x	x	x	x	x														x	x																	x	x	x	x		
	AS2	x	x	x	x	x														x	x																	x	x	x	x		
	AS3	x	x	x	x	x														x	x																	x	x	x	x		
	CPN1	x	x	x	x	x																							x	x	x							x	x	x	x	x	
	CPN2	x	x	x	x	x																							x	x	x							x	x	x	x		
	CPN3	x	x	x	x	x																																					
	IP1	x	x	x	x	x									x	x				x	x													x				x	x	x	x		
	IP2	x	x	x	x	x									x	x				x	x													x				x	x	x	x		
	IP3	x	x	x	x	x									x	x				x	x													x				x	x	x	x		
	PI1	x	x	x	x	x																																					
	PI2	x	x	x	x	x																																					
	PI3	x	x	x	x	x																																					
	PI4	x	x	x	x	x																																					
Landscape enhancement	UE1	x	x	x	x	x																																					x
	UE2	x	x	x	x	x																																					

Figure 9. Different priorities attributed to the clusters, screenshots from *SuperDecisions* software: (a) Local economy; (b) Shared urban green promotion; (c) Local self-production; (d) Social self-production.



close ranking values (Figure 10). For this last option, a sensitivity analysis is conducted, aiming at better addressing the result. The results are not very much influenced, when changing weights, that is, in ANP model, changing node for sen-

Figure 10. Different rankings according to the priorities, screenshots from *SuperDecisions* software: (a) Local economy; (b) Shared urban green promotion; (c) Local self-production; (d) Social self-production.

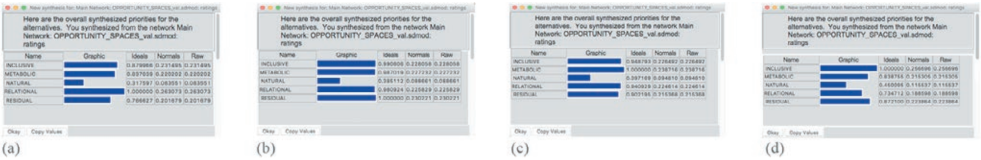


Table 4. Opportunity-spaces, processes and synergies.

	Relational	Metabolic	Residual	Inclusive	Natural-non-anthropised
Processes	Local economy; Shared urban green promotion	Local self-production; Shared urban green promotion	Social self-production; Shared urban green promotion	Social self-production; Shared urban green promotion	Landscape enhancement and protection
Synergies	Local enterprises, Local administration, Cooperatives of inhabitants	Cooperatives of inhabitants	Open community of inhabitants, Cooperatives of inhabitants	Open community of inhabitants, Cooperatives of inhabitants	Local associations and local administration

sitivity, with two exceptions: when choosing CG2 indicator – *Abandoned green areas of uncertain property* – as a node for sensitivity, *Metabolic, Inclusive, Residual* spaces have almost the same values, while *Residual* spaces have the lower one; on the contrary, when choosing S1 indicator – *Density of relationships and people meeting in space* – *Residual* spaces obtain the highest value. The evaluation results are synthesised in Table 4.

Furthermore, the obtained results highlight how processes of circularity can be addressed, by enhancing existing processes of self-organisation among people, individual and community actors, whose cooperation is fundamental for the activation of systemic self-regenerative mechanisms. Starting from the strong connection between collective spaces within peri-urban areas and the relational pattern, detectable in these spaces, the opportunity-spaces evaluation allows linking the socio-spatial dimension with circular and self-renewable processes, based on the implementation of social synergies. At a local scale, the activation of processes of shared urban green promotion and landscape protection could involve cooperatives of inhabitants in the collaborative maintenance of green areas, which, enabling social negotiation and cooperation, would result in the local managing of green resources and waste and in the implementation of a much more symbiotic relationship between urban space and green infrastructures. The formation of local enterprises could define new business models, building a constant conversation with the inhabitants, about their needs and habits, aiming at offering them missing or new services. Processes promoting the production of social and community bonds and spaces would reverse the development logic based on the maximisation of economic capital, allowing the production of social capital and new intrinsic values. At a territorial and urban scale, the activation of the mentioned processes could lead towards a synergic dialogue among cooperatives of inhabitants-stakeholders and the local administration, providing the base on which CE strategies could be implemented on a wider scale, through a bottom-up regulation of systems of rules and policies.

5. Discussion and Conclusion

The research aims at proposing a multi-methodological approach for the interpretation and evaluation of peri-urban hybrid territories, through an autopoietic thinking. The literature that studies and evaluates social ecosystems complexity – shifting its categories from the vital mechanisms of natural ecosystems – refers to their capacity to activate and self-regenerate processes, while establishing connections among the elements (Luhmann, 1986; Zeleny and Hufford, 1992; Quick, 2003; Bača, 2007; Zeleny, 2009; Schatten, Bača, 2010). The network of connections and relationships is what makes the system adaptive (Gunderson and Holling, 2002; Locurcio et al., 2019), the diversity of its components makes it resilient (Costanza, 1992), the dynamics of shared and interdependent activities and practices make it productive, alive (Hardt and Negri, 2011). The study interprets the spatial heterogeneity of the analysed area as a physical manifestation of an entropic and productive mechanism, whose functioning depends on the territory capacity to allow the establishment and growth of a systemic and adaptive network of relationships among people. As a consequence, reading and evaluating this territory through spatial opportunities means understanding and measuring its metabolic capacity to self-regenerate, strengthening the intangible connections, that people establish within a place and among themselves, by using collective spaces. In this sense, the concepts of natural ecosystem self-renewability and CE renewable closed-loop processes (Stahel, 1982) have driven the research towards the evaluation of self-regenerative territorial capacities and opportunities, based on social capital self-production (Cerreta, 2010).

The first methodological step identifies opportunities in space by measuring its entropic physical characteristics and detecting its relational dynamics. Entropy index constitutes a fundamental measure of territorial complexity: here, its application attempts to provide a measure not only of landscape complexity – as in the case of wooded and residual green areas – but of public and shared built spaces, as well. The effectiveness of the defined *Anthropic entropy index* depends on the categories and types of analysed characteristics: the empirical surveys collected just a few of the many spatial characteristics, aiming at making space informal and spontaneous uses evident. Choosing different categories of elements and characteristics could probably make the spatial interpretation vary. As regards the relational dynamics spatialization, it is based on empirical and subjective data, as well – activity and behavioural mapping and interviews – and its results are very sensitive to observations duration and days. However, this approach results to be useful to deeper understand the reinvented use of collective spaces and abandoned areas, and the role that these ambiguous hybrid spaces play in the peri-urban system and how they influence people's daily habits.

The second step aims at providing a site-specific declination of SDG's indicators categories, referring to social and community empowerment – in particular, Goal 11^{th} – through the production of inclusive and resilient spaces. The set of selected indicators draws a parallel among SDG's categories and those of organisation, resilience and vitality, deriving from the natural ecosystem literature. The O-R-V indicators are, here, referred to with a spatial-social meaning, and address the evaluation towards intangible values. This phase constitutes the methodological base for the intrinsic-value-based evaluation. O-R-V indicators refer to wide territorial issues but allow to think through ecosystems categories: the system structure and network of informative connections; the diversity and heterogeneity of the system components; the system self-production capacity. In terms of social and common urban systems, these categories can be understood as: cooperation and self-organisation; inclusion and acceptance of externalities, and social creativity; social self-production capacity. The criticalities emerging in this phase refer to the inconsistency of some of the data, collected through semi-structured-interviews: the qualitative indicators values result from the processing of reduced number of interviews, compared to the total number of conducted interviews. For this reason, in order to develop the research, it could be useful to integrate the proposed methodology with other evaluation methods, taking into account other types of measurement, such as linguistic and fuzzy judgements.

The application of ANP network model for the opportunity-spaces evaluation allows: taking into account the relative interdependences among the structure elements, underlining, for example, the close relationship among services, space uses and sociability, and participation in space definition processes; considering the dependences of many different indicators to the ones related to social practices and behaviour in space. The results are very sensitive to the network structure and to the chosen priorities and weights, suggesting how decisions, according to the identified opportunities, depend very much on the interests and possible synergies involved in the local processes catalysation: a collaborative table for the weights attribution would potentiate a so structured model. However, if on one hand, ANP method is very useful to grasp the complexity of the proposed issues related to peri-urban systems, on the other, its downsides emerge when it is applied through the direct involvement of stakeholders in the decision-making process: the decision problem modelling would become more difficult and the network more complex; the questionnaires filling could require more time and effort, to define the priorities among criteria and indicators; as a consequence, the decision problem results could become of much more problematic interpretation.

Finally, the chosen categories of opportunity-spaces are indicative of local mechanisms and depend on the specific detected characteristics: further researches could improve the definition of these categories, constituting a decision support system for peri-urban territories, and addressing processes of territorial heterogeneity enhancement and local communities empowerment, toward the establishment of local *eco-communities* consistent with CE processes.

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Appendix A

In Table A1 (Table A1), the indicators values are reported. As explained in (*4.2*), they have been measured within chosen example opportunity-spaces for each type.

Qualitative indicators are expressed through a 0-3 scale, with: 0 = non-present quality; 1 = modest quality; 2 = significant quality; 3 = very significant quality.

Table A1. Indicators values.

Indicator code	Measure unit	Relational	Metabolic	Residual	Inclusive	Natural-non-anthropised
LA1	number	3	1	0	0	2
LA2	number	2	0	0	0	0
LA3	number	6	1	0	0	0
LA4	number	4	1	0	1	2
CP1	number	4	2	2	1	2
CP2	m^2	3.026,22	1.285,39	587,68	651,29	0,00
CP3	m^2	1.738,93	193,29	206,36	464,28	0,00
CP4	m^2	188,23	99,27	0,00	0,00	0,00
S1	0-3	3	2	1	3	0
S2	0-3	3	1	1	2	1
CG1	m^2	184,28	3.268,27	4.233,58	199,73	0,00
CG2	m^2	53,29	2.495,39	8.239,37	0,00	0,00
CG3	m^2	1.235,64	2.465,78	3.760,39	0,00	0,00
N1	0-3	1	2	3	2	0
N2	0-3	2	1	3	2	0
MU1	number	3	5	1	1	1
MU2	number	2	4	3	2	1
TU1	number	1	3	2	1	1
TU2	number	2	4	2	1	1
C1	0-3	1	3	2	2	1
C2	0-3	1	3	3	2	1
C3	number	1	3	2	1	0

Indicator code	Measure unit	Relational	Metabolic	Residual	Inclusive	Natural-non-anthropised
AS1	m^2	0,00	331,28	125,39	942,34	0,00
AS2	number	2	8	3	12	0
AS3	m^2	52,30	0,00	0,00	218,29	0,00
CPN1	number	1	2	2	3	1
CPN2	0-3	1	1	2	3	0
CPN3	0-3	1	2	3	3	0
IP1	0-3	2	1	2	3	2
IP2	0-3	1	1	2	3	0
IP3	0-3	1	2	2	3	2
PI1	0-3	1	1	2	3	2
PI2	0-3	1	2	2	3	2
PI3	0-3	1	1	2	3	2
PI4	0-3	2	2	2	3	2
UE1	m^2	0,00	0,00	0,00	0,00	210.472,93
UE2	number	0	2	5	0	15

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Climate change and urban well-being: a methodology based on Sen theory and imprecise probabilities

The phenomenon of urban heat waves are becoming a significant public health problem in the summer season. Global warming is therefore not only an environmental problem, but also an ethical and political issue of climate justice. The research was based on the capability approach developed by Amartya Sen. The aim of the study is to (1) identify a set of indicators that allows to estimate the risk of decreased individual well-being; (2) implement these indicators in a probabilistic model that allows to explicitly consider the lack of certain knowledge on the effects of climate change; (3) provide high resolution urban mapping for climate change adaptation strategies.
The research focused on the vulnerable people (elderly people and children) in the city of Rosignano Solvay.
The combination of the results, obtained through the aggregation Dempster's rule, allows to identify the most critical areas on which it is necessary to intervene or through mitigation or urban regeneration.

1. Introduction

Climate change certainly has several consequences for human health, both direct and indirect. High temperatures can cause respiratory and cardiovascular problems among children and elderly, also leading the elderly to premature deaths (Zhang, McManus and Duncan, 2018). Different types of extreme weather events affect different regions: for example, heat waves are a problem especially in southern Europe and the Mediterranean, but also, to a lesser extent, in other regions. This phenomenon affects the thickness of the atmosphere and causes warm air subsidence, abnormal air heating and a stable urban heat island (UHI) in the region (Ghobadi et al., 2018). Therefore, the phenomenon affects cities livability and influences the ways in which its outdoor spaces are used. Especially, public spaces intended for use by pedestrians and cyclists, such as parks, squares, residential and commercial streets, and foot and cycle paths are used and enjoyed more frequently when they have a comfortable and healthy climate.

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The Intergovernmental Panel on Climate Change (IPCC) reports that heat waves increased toward the end of the 20th century and are projected to continue to increase in frequency, intensity, and duration worldwide (Meyer et al., 2014), leading to future increases in illnesses and mortality. The extended exposure to extreme heat can severely affect a person's physiological comfort, causing heat stress (Aminipouri et al., 2016; Mortensen et al., 2018; Reid et al., 2009), resulting in influence on the ways in which the people use the outdoor spaces, in particular public spaces intended for use by pedestrians and cyclists (e.g such as parks, squares, residential and commercial streets, and foot and cycle paths). Therefore, the research is increasingly focused on the analysis of the spatial distribution of temperatures in urban areas, on the analysis of measurements of mitigation and adaptation to climate change, on adverse health impacts from heat waves and on the identification of the most vulnerable population groups to heat, to identify some useful guidelines to prevent harm. According to Isoard and Winograd (2013), the adaptation strategies in Northern Europe they are based on the ecosystem by small-holder farmers (Sweden); in mountain areas on insurance policies against natural hazards (Switzerland); in Central and Eastern Europe on the restoration of the lower Danube wetlands to manage flood risks; in Northwest Europe on flood risk management in the Scheldt estuary (Belgium), on adaptation strategies based on the ecosystem and green infrastructure (Netherlands), on the restoration of peatlands (Ireland), on the management of flood risk and the Thames Barrier (United Kingdom) and on floods, fresh water and the Dutch Delta Programme (Netherlands). Finally, in the Mediterranean Region they are based on technological, monitoring and survey actions as part of Integrated coastal management (France), on desalination for water supply (Spain), on new varieties and production systems in the wine sector (Spain), on regional early warning systems supporting people's health and safety (Italy). Indeed, it is important to consider that global warming is not only an environmental problem, but also an ethical and political issue of climate justice. This is because the effects of global warming not only affect the ecosystem - the life of plants and animals - but also that of human beings. For these reasons in 2000, at the same time as the United Nation Climate Change Sixth Conference of the Parties (COP 6), the issue of Climate Justice was defined. Climate Justice therefore means the moral obligation to create a more just and equitable world starting from the protection of human rights, and in particular of those populations that suffer most from the effects of climate change, even though they are not directly responsible for them (Opinion of the European Economic and Social Committee on "Climate Justice", 2017).

Theories of climate justice have produced important methodological approaches at a global level, for example the polluter pays principle (UNCED, 1992) and the models of distribution of emissions, but these models have limits because they are mainly focused on prevention/mitigation structures, leaving the crucial dimension that regards how we can really adapt to the growing effects of climate change strongly underestimated (Hughes, 2013).

To bridge the gap between the ideal and abstract notions of the theory of justice and the reality of defining social policies, the capability-based approach developed by Amartya Sen and Marta Nussbaum (1993) was introduced. This approach takes into account the local/individual sphere as it is based on what individuals are capable of doing. (Robeyns, 2016). Sen has directly addressed the issue of the environmental basis of existing capacities by recognizing that «*variations in environmental conditions, such as climatic circumstances (temperature ranges, rainfall, flooding, and so on), can influence what a person gets out of a given level of income.*» (Sen, 2014, p. 70). Therefore, environmental circumstances can have a significant impact on individuals' ability to use resources and build social relationships. By extending the list of capabilities proposed by Nussbaum in a framework to deal with climate change, Edward Page (2007) proposes the addition of an ability to live in a safe and hospitable environment. Holland (2008), on the other hand, underlines the way in which the capabilities on the Nussbaum list depend directly on a stable climate system. Schlosberg (2012) stresses the importance of mapping vulnerability can help us understand the expected environmental impacts and threats to basic human capabilities that are based on the continuous functioning of environmental processes and conditions. This vulnerability mapping can be used to design policies that address these vulnerabilities. A committed reflection process that assesses vulnerability can be used to clarify which policy responses are most needed in particular areas and where resources will be applied more appropriately on separate issues. Similarly Lindley et al. (2011) define the concept of socio-spatial vulnerability. «*Socio-spatial vulnerability brings in aspects of place and time with personal, social and environmental factors resulting in the geographical expression of the degree to which an external event has the potential to convert into well-being losses*». (Lindley et al., 2011, p.6). (Heat waves)

Heat waves do not depend on the absorption of solar energy by asphalted and concrete surfaces as for the urban heat island (UHI), but are extreme weather conditions that occur during the summer season, characterized by high temperatures at the above the usual values, which can also last for a long period. It is considered an extreme climate which can be a natural disaster and a danger because heat and sunlight can overheat the human body (Kyselý, 2002; Meehl and Tebaldi, 2004; Theoharatos, 2010).

The aim of the study is to (1) identify a set of indicators that allows to estimate the risk of decreased individual well-being following significant changes in access to the basic capabilities of Sen and Nussbaum; (2) implement these indicators in a probabilistic model that allows to explicitly consider the inaccuracy and the lack of certain knowledge on the effects of climate change; (3) provide a methodological approach to define a high resolution urban mapping suitable to drive climate change adaptation strategies aimed to reduce heat related risks for the vulnerable population and prevent their health risks. The research focused on the social groups most vulnerable to heat waves: elderly people over 65 and children, in a case study represented by Rosignano Solvay town, a little-size city located on central Italy.

2. Methodologies

2.1 The capability approach to urban climate risk

Amartya Sen's capability approach focuses on the substantial freedom of people to pursue their vision of individual well-being. According to the theory outlined by Amartya Sen, the well-being of the individual is defined by the human "functionings" and the "capabilities" to achieve it. Functions are what a person is able to do or be given his income, but also his personal characteristics (e.g. his state of health) and the characteristics of the environment in which he lives. A person's capabilities, by contrast, reflect «*the alternative combination of functionings [they] can achieve, and from which he or she can choose one collection*» (Nussbaum and Sen, 1993,p. 31). «*Capability*», Sen writes elsewhere, «*is a kind of freedom: the substantive freedom to achieve alternative functioning combinations*» (Sen, 1999, p.75). Sen argues that each person should enjoy roughly similar sets of capabilities to achieve a comparable level of well-being.

Sen's approach to capabilities was further developed by Martha Nussbaum. A central pillar of Nussbaum's theory of justice is the definition of a classification of capacities. While Sen provides numerous examples of capabilities and functions, he has so far refused to offer a systematic list of capabilities or to define their relative importance. Nussbaum, on the contrary, identifies a list of 10 "central human functional capacities": life; bodily health; bodily integrity; senses, imagination and thought; emotions; practical reason; affiliation; relationship with other species; play; political and material control over one's environment (Nussbaum, 2006a, 2006b).

A strength of capability theory is that it potentially leads to a detailed description of the impact of climate-related events on individual well-being. With regard to heat waves, high temperatures affect all individuals in a given area, however the conversion of the extreme event into a loss of well-being will depend on how personal, social and geographic characteristics affect individuals. Let us first consider the fundamental ability of Nussbaum "Bodily health". With regard to personal characteristics, the elderly and children will be more vulnerable. Taking into account the social characteristics, poor, lonely or foreign people will have less chance of implementing family adaptation strategies (Robeyns, 2005).

However, the geographical characteristics of the urban environment can also influence the variation in well-being from the heat wave. The distance that you need to travel outdoors during an extreme climatic event to go to church, shops or other places of social life can represent a discomfort so serious as to limit the freedom of individual behaviour. This affects important capabilities such as "Senses, Imagination, and Thought", "Emotions", "Affiliation", etc.

In our research, we therefore classified the indicators into two vulnerability sub-set referring exclusively to the vulnerable population (elderly and children): vulnerability deriving from people's socio-economic conditions and vulnerability deriving from the risk of exposure to heat waves in outdoor activities. The first sub-set derives from the socio-economic characteristics of the elderly and children

Table 1. Social vulnerability and exposure vulnerability indicators.

Population	Indicator	Data source
Elderly	*Social Vulnerability*	
	Density population 65-69 years old Density population 70-74 years old Density population over 74 years old Density of low education Density of widower Density of population for rent	Census data (ISTAT, 2011)
	Exposure vulnerability	
	Churches distance Bus stop distance Medical studies distance Pharmacies distance Food services distances Supermarkets distances	GIS data analysis (Open Street Map)
	Urban climate safety	
	Urban climate safety	Comfort index (Barbierato et al. 2019)
Children	*Social Vulnerability*	
	Density population less 5 years old Density population 5-9 years old Density of low education Foreigners	Census data (ISTAT, 2011)
	Exposure vulnerability	
	Schools distance Urban parks distance Sport areas distance	GIS data analysis (Open Street Map)
	Urban climate safety	
	Urban climate safety	Comfort index (Barbierato et al. 2019)

population, while the second from the risk of exposure deriving from the distance between the commercial, social and transport services and the places of residence of the sensitive population(Inostroza et al., 2016).

According to the literature (Eisenman et al., 2016; Fraser et al., 2017; James et al., 2015; Krellenberg, et al., 2015; Loughnan, et al., 2014; Mendez-Lazaro et al., 2018; Morabito et al., 2015; Reid et al., 2009; Uejio et al., 2011; Zhang et al., 2018) we have identified the set of urban vulnerability indicators of sensitive people shown in Table 1. For the first set of indicators the demographic and socio-economic variables investigated included age, poverty, education level and living alone. For the second set of indices we calculated the pedestrian distances from churches, bus stop, pharmacies and medical offices. The highest vulnerability of the elderly to heat is related to age, because they dehydrate themselves more easily due to age-related reduced thirst and the capacity to conserve salt and water (European Topic Center on Climate Change Impacts, Vulnerability and Adaptation, 2012). In the paper we considered three class of elderly population (65-69 years old, 70-74 years old, over 74), starting from the assumption that the greater the age the greater the vulnerability to heat. In according to Krellenberg, et al. (2015), Mendez-Lazaro et al. (2018), Reid et al. (2009), the higher the educational level, the lower the vulnerability as higher educational level contributes to better knowledge about natural extreme events and the ability to anticipate and resist. For these reasons we chose illiterate, population with primary school and with secondary school to identify as low level of instruction to identify the vulnerable people.

Other factor concerned the household composition, because people living alone are more vulnerable to heat (Eisenman et al., 2016; Reid et al., 2009; Uejio et al., 2011; Zhang et al., 2018). Renters often have little autonomy and surplus for mitigation measures, may lack capacities to cope with consequences of a hazardous incident (Cutter et al., 2008; Jean-Baptiste et al., 2011). In additional to these factors, we considered also the pedestrian distance from a principal services that a heat sensitive person is used daily to attending (Eisenman et al., 2016; Fraser et al., 2017; James et al., 2015; Krellenberg et al., 2015).

Following Page (2007a, 2007b) the list of capabilities proposed by Nussbaum can be extended to address the problems of future climate change by expanding the list to include a new capability «*to represent the value a person derives from operating within a hospitable natural environment….Here, we view a safe and hospitable environment as a vital ingredient of a decent life rather than a facilitator of other functionings such as 'play', 'emotions' or'control over one's environment' (which, despite its label, has no direct connection to environmental values). ... On this view, we should value a hospitable environment because it is an integral feature of a life of decent quality and not because it facilitates desire satisfaction.*» (Page, 2007b, p.464).

In our work we therefore considered a specific indicator to evaluate the capability of people to live in an urban environment with a safe and hospitable climate in public spaces (streets, squares and urban parks). To evaluate the urban climate safety, we analyzed the current land surface temperature of the study area and the temperature perceived by people through a climatic comfort index. The geodatabase used for the construction of our index was a high resolution (1 meter) land surface temperature map (LST), calculated on a day of urban heat wave. The basic spatial data at 1 meter resolution is crucial for the entire development of the methodology, because the unit used to also create the membership classes by geolocalizing the fuzzy indicators.

The main feature of the map is to consider the effect of the presence of the urban green, the bodies of water and the shadow of the buildings on the surface temperature (for more details see Barbierato et al., 2019). The date of the heat wave to which the map refers is August 8, 2017, it falls within the 95th percentile of the frequency distribution of the maximum daily temperature in the last 14 years of survey of the weather station of Quercianella (a town 9 km away from

Rosignano). It should be noted that the date of August 8 is purely representative of an increasingly probable generic heat wave day (for a review see Ummenhofer and Meehl, 2017). On this day, the LST in the urban area of Rosignano recorded a median of 33.8 °C and a range of 28 °C for the first quartile (in the shade of the tree crowns) and 37 °C for the third quartile (in the east-west oriented roads). The LST map has been converted into a Thermal Sensation Index (TS) map based on the procedure proposed by Givoni et al. (2003):

$$TS = 1.7 + 0.1118 \cdot T_a + 0.0019 \cdot RS - 0.322 \cdot v - 0.0073 \cdot RH + 0.0054 \cdot T_{ss} \quad (1)$$

where T_a is air temperature in °C, *RS is the* horizontal solar irradiance in W/m^2, v is the wind speed in *m/s, RH is the* relative humidity in %, T_{ss} *is the* surrounding soil temperature in °C. The index is defined as the perception of cold or heat, on a scale ranging from 1 (very cold) to 7 (very hot). Level 4 is comfortable, which means the human body feels no thermal discomfort.

2.2 *Imprecise probabilities and Dempester-Shafer theory*

Climate change assessments and the development of response strategies are hampered by multiple uncertainties and lack of knowledges. Some sources of uncertainty can be represented by objective probability density functions. There are, however, limits to the deterministic description of the phenomenon given that the set of consequences of urban heat waves on individual well-being is certainly not a stationary system. The reliability of knowledge of uncertain aspects of the world (such as the "true" value of climate vulnerability) cannot therefore be represented by objective probabilities.

One method to characterize the uncertainty due to the lack of scientific knowledge is the Bayesian (or subjective) probabilities, which refer to the degree of credence of the experts, considering the available data. Caselton and Luo, (1992) argue that decision problems related to climate change are decision-making processes in conditions of "almost ignorance". "Almost ignorance" occurs when "*the total information brought to bear on the decision problem is sufficiently weak to present difficulties with conventional uncertainty analyzes.*"(Caselton and Luo, 1992, p. 3071) Numerous approaches have been proposed in the literature to overcome the limitations of the Bayesian scheme, considered too rigid to deal with problems in conditions of "almost ignorance" through the generic concept of "imprecise probability" (Walley, 1991). In the context of climate change vulnerability analyzes (the scheme that has been most widely applied is the theory of Dempster Shaffer (DST) (Dempster, 1967, 1968a, 1968b, 1969; Shafer, 1976, 1982).

The DST derives from the Bayesian theory of subjective probabilities and allows the combination of different lines of evidence that originate from various sources of knowledge and information in order to obtain degrees of belief for different hypotheses. In our study we have defined two lines of evidence: the first, H1: climate vulnerability, is related to the probability that a vulnerable person (elderly or child) will cross a generic urban place outdoors on a heat wave day; the second, H2: urban climate resilience, is linked to the probability that the same position has microclimatic characteristics (presence of urban greenery, high ratio between the height of the buildings and the width of the road, north-south orientation of the roads, etc.) that reduces the health risk for the elderly and children.

The treatment of uncertainty in DST focuses on the concept of "plausibility". The Bayesian formulation represents the starting point of the treatment of the notion of plausibility in DST; the two approaches share the idea that plausible reasoning is a type of uncertain reasoning because it is carried out using sources that provide information characterized by a degree of reliability but not of certainty. Unlike Bayesian probabilities, DST does not need complete information in the event space; therefore, this theory allows the use of two different values to express belief in a specific proposal, or belief in its negation.

If we have two lines of evidence H1 and H2, the concept of DS subjective probability (p) differs from the concept of Bayesian probability because for two lines of evidence in the DS theory we will have:

$$p(H1) + p(H2) + p(H1,H2) = 1 \text{ and thus } p(H1) + p(H2) < 1, \tag{2}$$

while in Bayes:

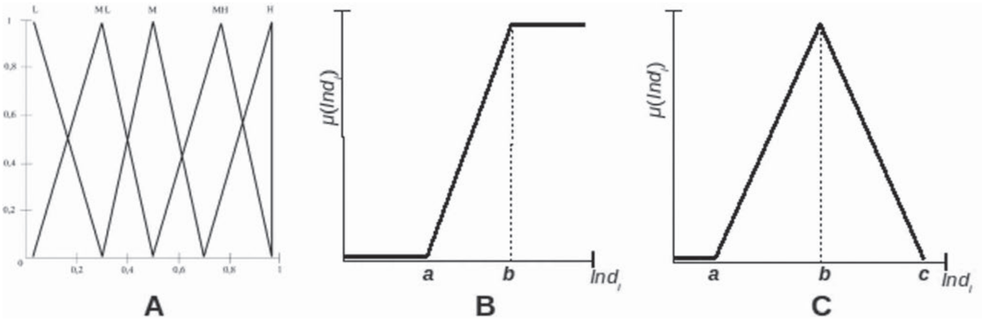
$$p(H1) + p(H2) = 1. \tag{3}$$

The remaining p(H1,H2) represents the contribution to uncertainty. The concept of DST lines of evidence differs from the concept of Bayesian probability because in Bayesian probability the sum of probabilities is constrained to 1 instead in DST the contribution to uncertainty is taken in account. In the DST we have high uncertainty when we have strong evidence of vulnerability and strong evidence of urban climate safety in the same location. The evaluation of the hypothesis is based on the concept of Basic Probability Assignment (BPA). The BPA represents the contribution that a certain factor i gives as a support for a specific line of evidence (for instance the vulnerability of a location). In our approach, the evaluation of BPA is based on the fuzzy functions (Yager, 1999) built on the indicators of table 2 and linguistic evaluators which were used in the model (expressed as a degree of belief). The evaluators were given by experts as oral terms (Bentabet et al., 2000); model formulation was explained in the following formula:

$$BPA_{i,x} = \mu_{linguistic}(Ind_i) \cdot \mu(x_i), \tag{4}$$

were $\mu_{\text{linguistic}}(Ind_i)$ is the linguistic assessment through a fuzzy linguistic evaluator of the contribute in the line of evidence of indicators i (Ind_i) and $\mu(x_i)$ is the assessment through a membership function of the environmental effect of the indicators i on the localization x. A membership function for a fuzzy set A on the universe of discourse X is defined as $\mu A{:}X \rightarrow [0,1]$, where each element of X is mapped to a value between 0 and 1. This value, called membership value

Figure 1. Linguistic fuzzy numbers: L=low, ML=medium-low, M=medium, MH=medium-high, H=high.



or degree of membership, quantifies the grade of membership of the element in X to the fuzzy set A. Membership functions allow us to graphically represent a fuzzy set. The x axis represents the universe of discourse, whereas the y axis represents the degrees of membership in the [0,1] interval (Porębski et al., 2016). We carried out the evaluation through linguistic quantifiers through a procedure that was carried out with the contribution of experts in the pediatric and geriatric medical sector. The opinions of three urban planning experts have been elicited using linguistic terms that can be expressed in trapezoidal fuzzy numbers. The evaluation of the variables was therefore implemented through a set of linguistic terms derived from Chen and Hwang's scale 3 (figure 1). The fuzzification of the indicators was based on the information deduced from the literature examined (Eisenman et al., 2016; Fraser et al. 2017; James et al., 2015; Krellenberg et al., 2015). Fuzzy functions have been applied to indicator maps through map algebra procedures. The maps are all at 1 meter of resolution. The basic probability assignment maps (BPA) were finally obtained through the product of each fuzzy map and the relative linguistic weight. The parameters of the trapezoidal fuzzy functions and the linguistic terms used are shown in table 2 (see also figure 1). For example, a low linguistic weight was attributed to the distance from schools factor to evaluate the well-being of children since in Italy, during the school period (from September to June of the following year), the season hit by the waves has a short duration.

For the line of evidence H1, urban climate vulnerability, all factors are progressively aggregated in pair using the orthogonal sum (Shafer, 1976) rule of combination:

$$BPA_x(i,j) = BPA_{i,x} \_|\_ BPA_{i,y} = \frac{BPA_{i,x} \cdot (1 - BPA_{j,x})}{1 - BPA_{i,x} \cdot BPA_{i,x}}. \quad (5)$$

The final result mass probability of urban climate vulnerability *m(H1)* is obtained by the follow procedure:

$$m(H1) = \_|\__{v}^{H1}(BPA_{v,x}) v = 1, \cdots, V \quad (6)$$

Table 2. Fuzzy function parameters.

Indicator	Linguistic assessment	a	b	c
Density of elderly population 65-69 years old	medium	0	15	
Density of elderly population 70-74 years old	medium-high	0	20	
Density of elderly population over 74 years old	high	0	36	
Density of low education population	low	0	97	
Density of widover	high	0	26	
Density of population for rent	medium-low	0	17	
Churches distance	high	250	1500	
Bus stop distance	medium	250	1500	
Medical studies distance	low	250	1500	
Pharmacies distance	low	250	1500	
Population density less 5 years	high	0	19	
Population density between 5-9 years	medium	0	16	
Foreign population density	low	0	18	
Distance from schools	low	250	1500	
Distance from urban parks and public gardens	medium	250	1500	
Distance from sports and recreation areas	medium	250	1500	
Urban climate safety	high	1	4	7

were _|_ is the orthogonal sum, $v=1,...,V$ are all indicators of vulnerability and $r=1,...,R$ are all indicators of urban climate safety.

For line of evidence H2, urban climatic resilience, it was calculated on the basis of the TS map using the following procedure:

$$m(H_2) = \mu_{linguistic}(TS) \cdot \mu(x_{TS}) \tag{7}$$

where $\mu_{linguistic}(TS)$ is the expert linguistic assesment of contribute of TS to the line of evidence, $\mu(x_{TS})$ is the membership function of urban cliamte resilience of TS in location x.

The aggregation of the two hypothesis *H1* and *H2* is performed adopting Dempster rule the uncertainty degree of location derive both from occurrence of high vulnerability and high urban climate safety in the same area:

$$\begin{aligned} Bel(H1) &= \frac{m_{H1} \cdot 1 - m_{H2}}{1 - m_{H1} \cdot m_{H2}} \\ Bel(H2) &= \frac{m_{H2} \cdot 1 - m_{H1}}{1 - m_{H2} \cdot m_{H1}} \\ U(H1, H2) = Bel(H2) - (1 - Bel(H2)) &= \frac{(1 - m_{H1}) \cdot (1 - m_{H2})}{1 - m_{H2} \cdot m_{H1}} \end{aligned} \tag{8}$$

Bel(H1) and Bel(H2) are belief of vulnerability and belief of urban climate safety measures; belief interval represents the uncertainty degree of location, deriving both from occurrence of high vulnerability and high urban climate safety in the same location. The adopted methodological framework is summarized in figure 2a and 2b.

3. Study area

The research was applied in the city of Rosignano Solvay a small city of Central Italy located on the Tuscan coast and overlooking the Tyrrhenian Sea. The study area has boundary coordinates (datum WGS84, projection UTM, zone 32) N min = 613253, N max = 618615, E min = 4803895, E max = 4807895, and mean latitude = 43.39°N.

Since the aim of the research is focused on the urban well-being and it is to provide an urban-scale mapping for adaptation strategies to climate change to reduce heat risks for the vulnerable population, the perimeter of the study area only takes into account the urbanized territory of Rosignano Solvay and Castiglioncello and it excludes: industrial areas to the south of the city, some neighbouring areas that are too far from the city centre and those that are on the border with rural areas have been excluded from the municipal territory (Figure 3).

The urbanized territories had a different urban and settlement development. The history of Rosignano Solvay revolved mainly around the soda plant opened in 1913 by the industrialist Ernest Solvay. An urban nucleus was immediately created around the plant, consisting of houses for employees and workers of the plant itself. With the expansion of the factory, the villages were also expanded, building some groups of houses beyond the railway line towards the coast, also enhancing services. The 1940s were decisive for urban development, since the frenetic building activity gave the industrial town its current image: the avenues, the trees, the squared lots, the vegetable gardens, the architecture and the pine forests constitute the typical "style Solvay " (Celati and Gattini, 1995).

While, the urbanized area of Castiglioncello is located in a privileged position from a panoramic point of view, far from the major communication routes, it remained unknown and uncontaminated until modern times, with its pine forests and cliffs close to the sea. Since the 1960s it has become a popular seaside resort, consisting of establishments and holiday homes and villas surrounded by greenery (Celati and Gattini, 1991).

The study area covers an area of 586 100 hectares, which 224 257 ha of urban green and the remaining part by artificial surface.

The territory of Rosignano Solvay falls in the "Hot-summer Mediterranean climate" class according to the classification of Köppen and Geiger. Regions with this form of the Mediterranean climate typically experience hot, sometimes very hot and dry summers. In this season the population, 20 340 total inhabitants in 62 census tract in according to ISTAT data on 2011 population census, is very vulnerable to heat waves, in particular the categories most at risk for heat-related health are

Figure 2a. Structure of the Dempster Shaffer model of the elderly population.

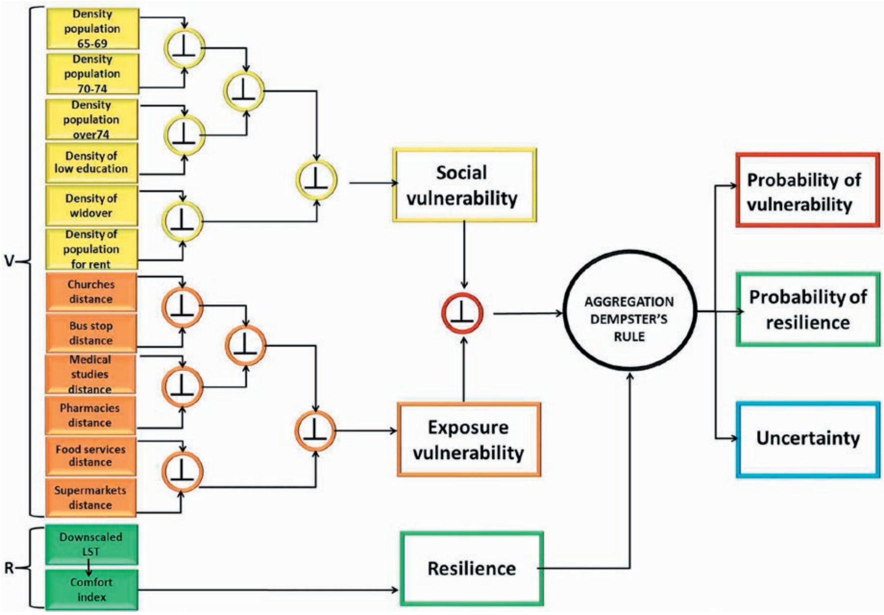


Figure 2b. Structure of the Dempster Shaffer model of the infant population.

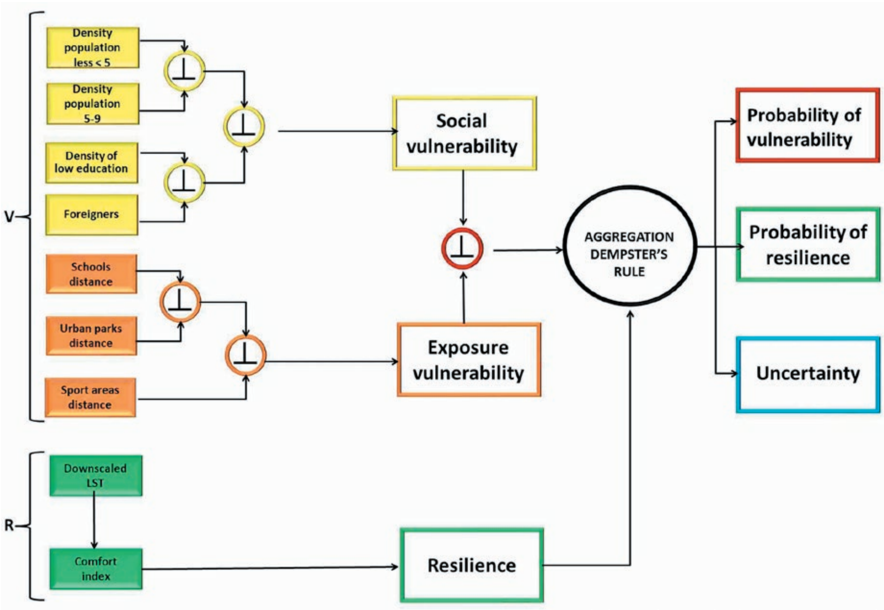
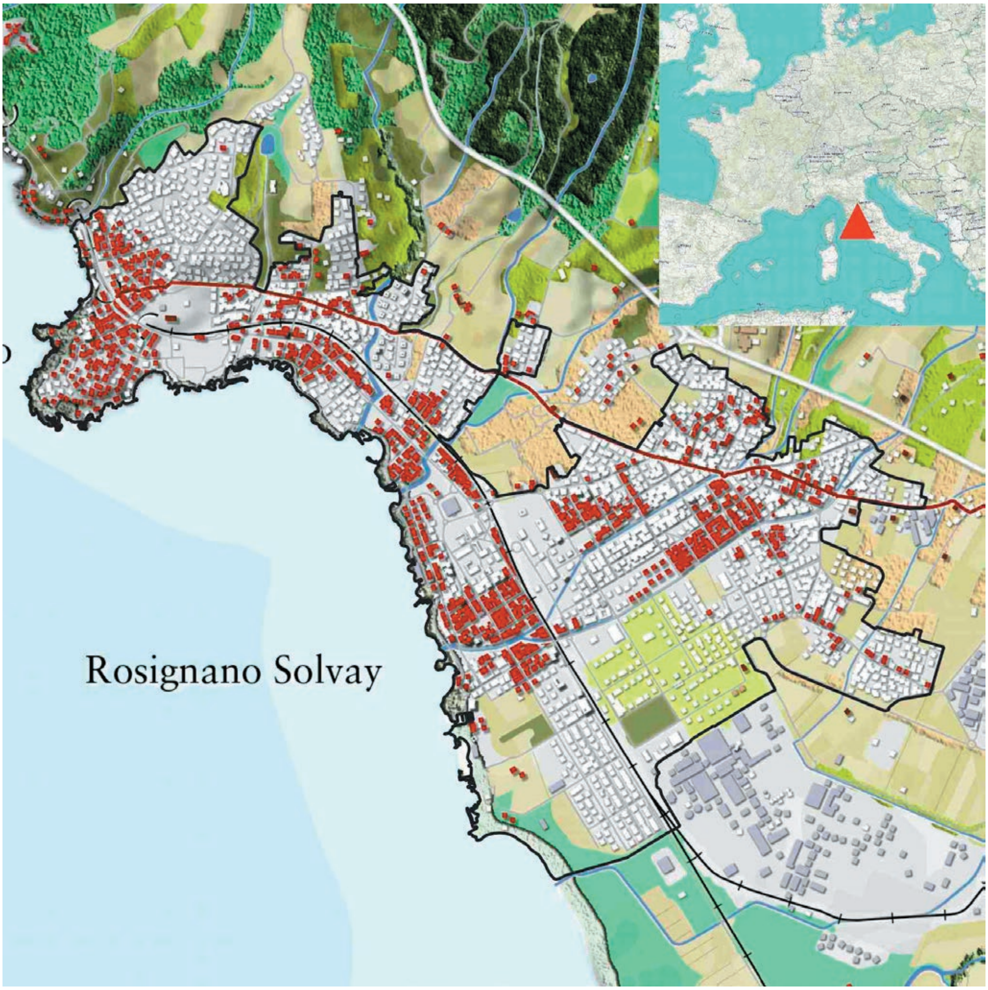


Figure 3. Study area.



the following: 7.70% children until 9 years old, 27.57% are people over 65 years old, 9.85% are widowed, 46.14% have low education, 10,82% are graduates, 5,11% are foreigners and finally 5.68% are rented families .

These two areas, although forming a continuous urbanized territory, have very different properties and building typologies also on the basis of the values of the real estate market. According to the Revenue Agency database (2019), in the south of the study area the civilian houses are between 1500 and 2100 €/mq, the economic houses between 1400 and 1900 €/mq, the villas between 2300 and 2850 €/mq. However, in the north the prices are significantly higher, because civil homes are between 1900 to 2650 €/mq, villas between 2300 and 3300 €/mq.

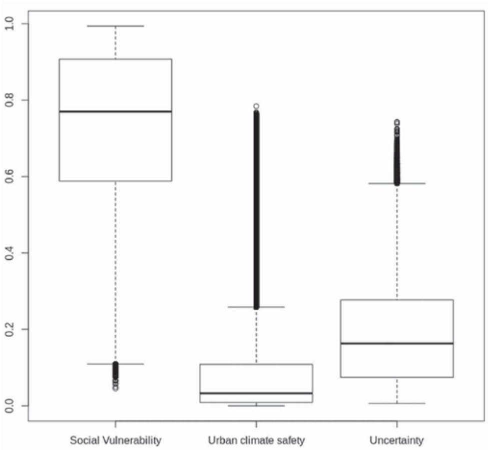
4. Results

Table 3 and Figure 4 show the parameters of the probability distributions calculated using the Demspter Shaffer model described in the previous paragraph.

The probability of having an elderly population in conditions of social vulnerability on a heat wave day reveals critical values, with an average of 0.72 and a median of 0.77. The distribution is also very asymmetrical towards high risk values, with the first quartile equal to 0.59. Even in the case of the infant population, there is a high risk of social vulnerability with a median of 0.71 and the first quartile of 0.5.

Even the chance to live in a safe urban environment for climate-being is severely impaired in a heat wave days. For the elderly we have a median of 0.08

Figure 4. Left: Boxplot of frequency distribution for Elderly. Right: Boxplot of frequency distribution for Children.



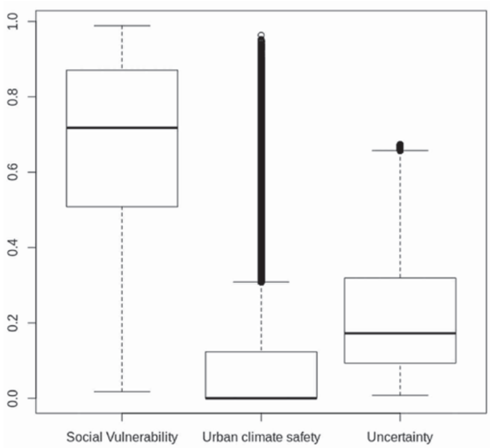


Table 3. Frequency distribution parameters of Belief of Social Vulnerability, Belief of Urban Climate Safety and Uncertainty for elderly and children.

	Elderly			Children		
	Social Vulnerability	Urban climate safety	Uncertainty	Social Vulnerability	Urban climate safety	Uncertainty
Min.	0.045	0.000	0.006	0.017	0.000	0.008
1st Quartile	0.588	0.009	0.074	0.508	0.000	0.093
Median	0.770	0.033	0.163	0.718	0.000	0.172
Mean	0.728	0.086	0.186	0.678	0.100	0.222
3rd Quartile	0.907	0.109	0.277	0.871	0.124	0.319
Max.	0.993	0.784	0.743	0.989	0.964	0.674

and a third quartile of 0.1, while for children we have 0.1 and 0.12 respectively. However, the two distributions have a relatively long right tail with maximum values of 0.78 for the elderly and 0.96 for the children; this shows that even on a day of climatic emergency there are areas in the study area that are likely to be a safe environment, because of the configuration of the space, the shape and height of the buildings and the presence of green areas and corridors.

The uncertainty of the two assessments is relatively low: for the elderly there is a median of 0.16 with the first and third quartiles equal to 0.07 and 0.28 respectively; for children there is a median of 0.17 with the first and third quartiles respectively equal to 0.09 and 0.32.

The general risk condition highlighted by the total results is geographically differentiated. Figures 5a and 5b highlights how the indicators of social vulnerability are higher in the south and south-east areas of the study area, in particular for the density of population with low degree of education, elderly people, widowers and rented families.

The climate comfort index (figure 6) also recorded safer values in the north area and in a part of the south area while the most critical values are concentrated in the south-east area.

This situation results in a strong inequality for the different areas of the city in relation to the risk of a decrease in well-being due to social vulnerability and a decrease in the capacity of living in a safe urban environment for both the elderly and children. In figures 7 and 8 the probabilities of social vulnerability, urban climate safety and uncertainty have been inserted respectively in the red, green and blue bands of an RGB image, thus generating a "false color" map defined by the triangular legend shown in the figures.

Figure 7 shows how the most critical situations for the elderly are located in the central-southern area of the city (colors from red to purple). This in fact presents a high probability of social vulnerability, a low probability of a safe climate environment and low uncertainty. The north-west area (unfortunately small in size) is more resilient to extreme thermoclimatic events (green colors), with good urban environmental safety values and low probability of social vulnerability. The areas where uncertainty prevails (colors from blue to purple) are relatively rare and scattered in the study area. The detail at the top right (figure 7b) shows that even in areas with the highest social vulnerability, the presence of public green areas considerably improves thermoclimatic well-being.

Figure 8 relating to the child population shows how the most unhealthy urban areas are located in different locations. In the central part of the city we have the prevailing uncertainty due to a contemporary low probability of social vulnerability, due to the good density of social services and low probability of urban safety climate, caused by the limited availability of public green. In the north, the situation is more critical, due to the high probability vulnerability caused by the distance from social services.

The false color maps, on the one hand spatialize the risk for the vulnerable population, identifying the most critical areas on which urban and territorial planning should take action primarily through climate adaptation actions; on the other

Figure 5a. Maps of indicators of social and exposure vulnerability for elderly.

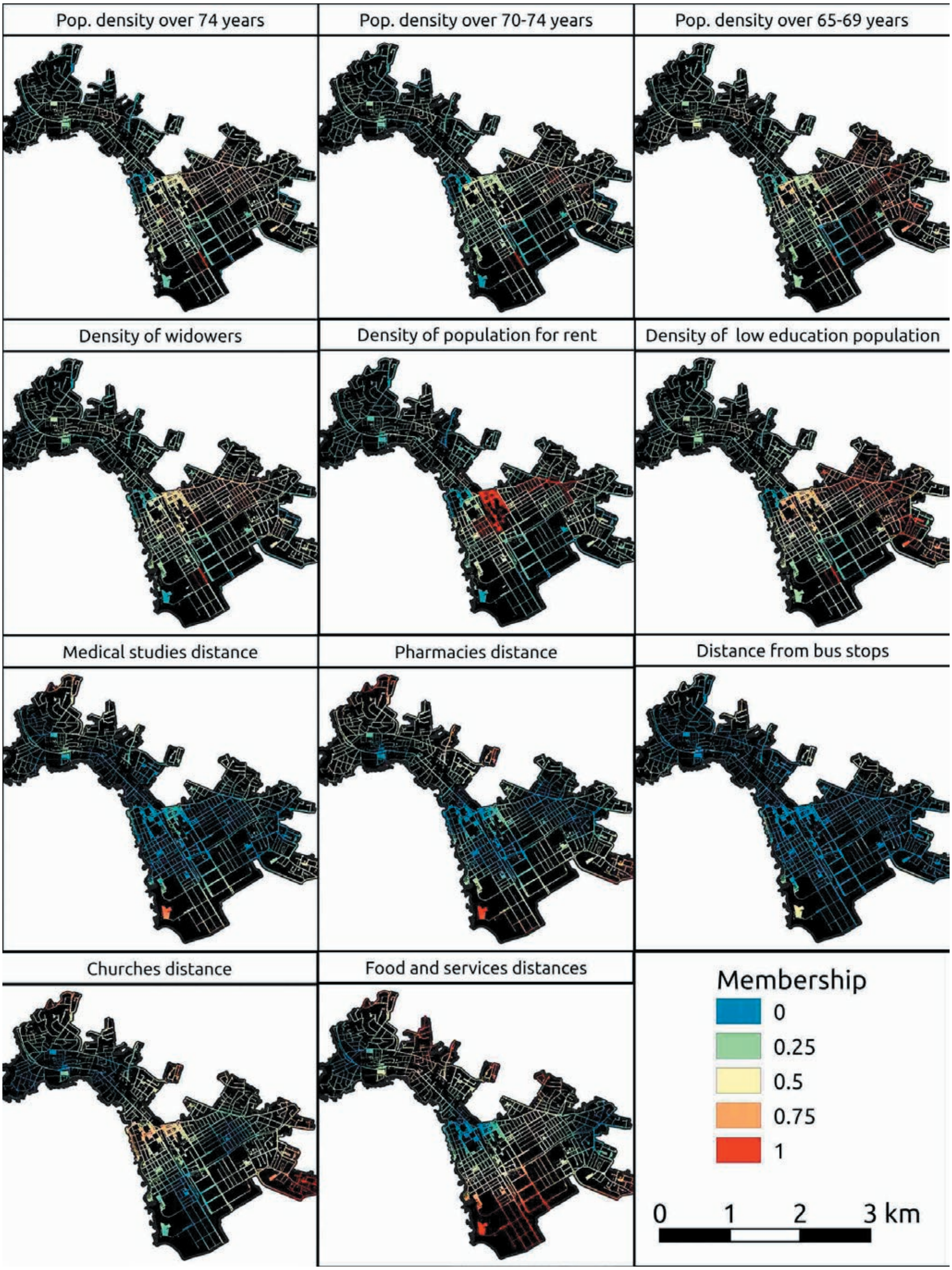
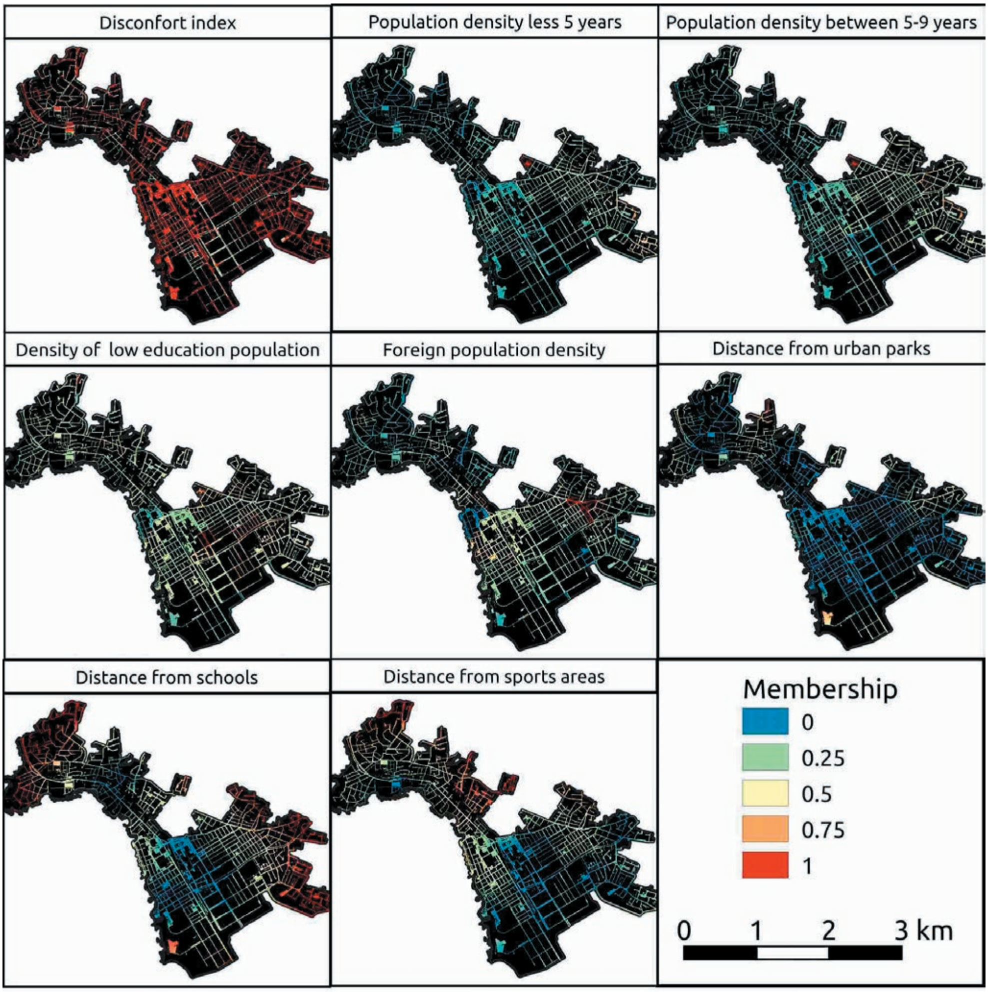


Figure 5b. Maps of indicators of social and exposure vulnerability for children.



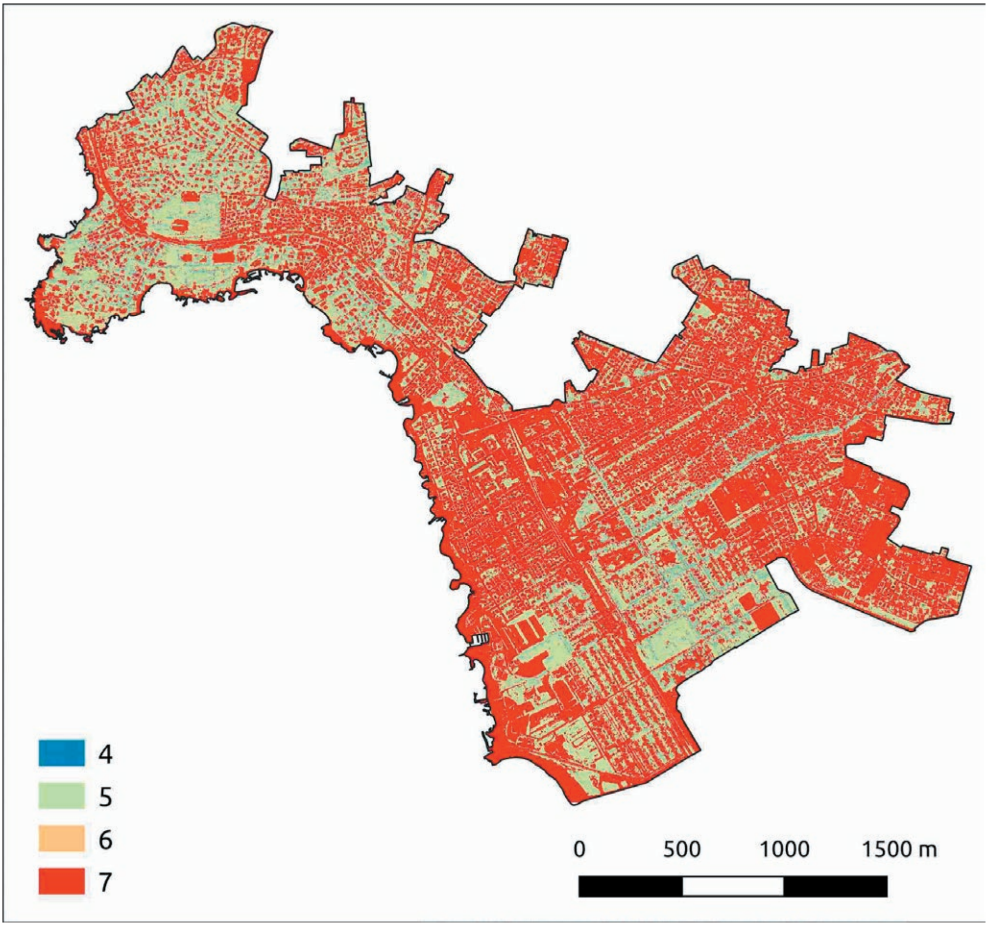
they highlight the positive effect of urban green in reducing the risk to health due to heat waves.

These results help urban and territorial planning to improve the resilience of Rosignano city and ensure a more livable city for all citizens, in particular for the most vulnerable population.

5. Discussion

The main contribution of this work is the identification of high resolution urban areas characterized by the risk of a decrease in well-being and in the social

Figure 6. Comfort index map.

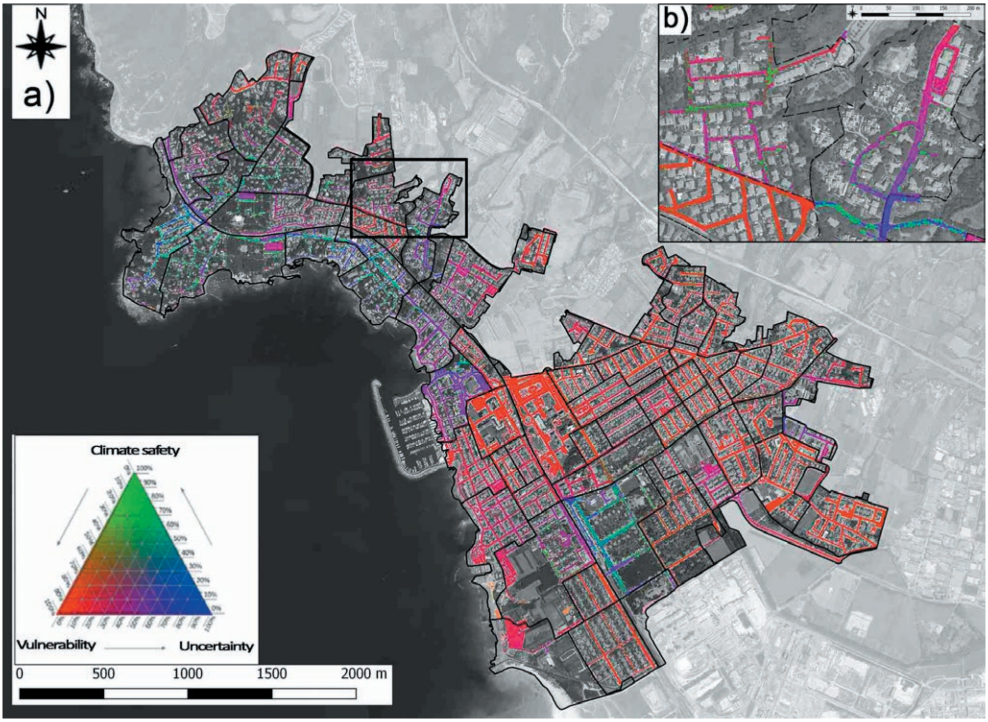


unease in days of extreme heat waves. The work focused on the socially most vulnerable groups i.e. the elderly and children.

The main innovation of this study is represented by the application of the theories of Sen and Nussbaum to the thermoclimatic well-being of urban areas. In according to Krellenberg et al, (2015), Wilhelmi et al. (2010) and Zhang et al. (2018), the capacity approach has in fact allowed to asses two main sources of inequality: the intrinsic factors or those due to the socio-economic conditions of vulnerable individuals and the extrinsic factors due to the characteristics of the urban environment. The most critical factors of environmental inequality were related to the distance from social services and to the temperature of public spaces on critical heat waves days.

Further significant evidence of climate justice is given by the fact that the freshest and livable areas are those with the highest real estate values, forcing

Figure 7. Elderly, false color composition: red = Social Vulnerability, green = Urban Climate Safety, blue = Uncertainty.



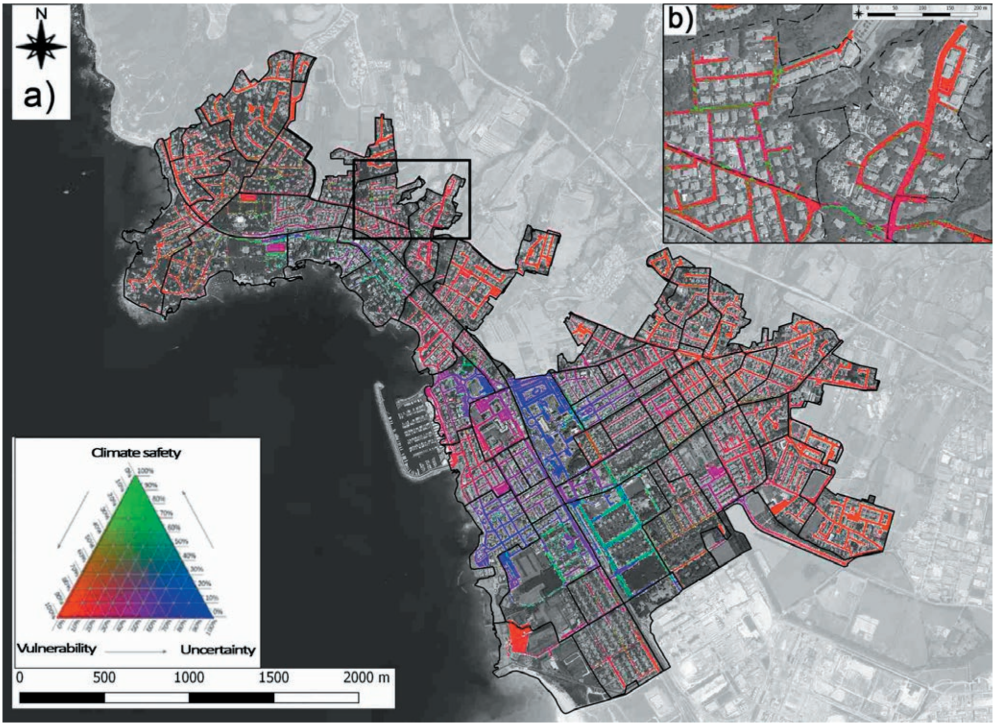
people to pay more for urban well-being. This highlights social disparities in the way individuals are vulnerable to the growing effects of climate change.

This information represents fundamental information to allow effective short-term intervention strategies such as the improvement of the availability of social services and medium/long-term intervention strategies such as the improvement of the albedo of buildings and the design of tree branches and public green areas to be part of the local authorities and urban planners when deciding heat-related health prevention actions at the level of small urban areas.

A second innovative element of the research is the use of an approach based on imprecise probabilities for assessing the reduction of urban well-being caused by extreme weather events. The use of the Dempster Shaffer methodology has allowed to probabilistically treat both the impact of heat waves on health risks for the sensitive population and the effect of the interaction between the different indicators that defined social vulnerability. Besides the possibility to explicitly measure the level of uncertainty allows to highlight the locations in which further investigation will be required.

This study also has some limitations. The social vulnerability of children and the elderly was assessed only through indicators derived from census data. On

Figure 8. Children, false color composition: red = Social Vulnerability, green = Urban Climate Safety, blue = Uncertainty.



the contrary, other socio-demographic and health variables (e.g. physiological adaptation, pre-existing health conditions, use of air conditioning, etc.) are important. Furthermore, information with finer spatial resolution than the census section would be used.

6. Conclusion

This study represents a starting point for identifying areas that require urban adaptation planning strategies. The main project dimensions that have emerged on which to base climate adaptation strategies in urban areas are:

- the increase in efficient public green spaces and corridors;
- the increase of public services;
- the use of high albedo materials;
- the design of new urban spaces with efficient dimensional ratios for temperature mitigation.

To try to limit the increase in temperature in the urban area during the summer season, it is appropriate to increase green surfaces, from large peri-urban parks to street trees, to the smaller interstitial spaces of more structured urban areas. The urban planning tools of the Municipalities must aim decisively to increase the green area and trees in all areas affected by urban transformations, starting from agricultural wedges to large extensive areas. In addition, the "green" furnishings for the redevelopment projects of public spaces must be added, with improved insulation.

Another solution is to approve guidelines for the use of materials that reduce the impact of climate change within neighborhoods. It has now been shown that building materials and choices can significantly aggravate climatic conditions. The floors can constitute up to 45% of the surfaces of a city and are often covered by asphalt and other dark materials that absorb more solar radiation increasing the urban heat island effect. On heatwave days these surfaces can reach very high temperatures, endangering the health of people, in particular the most vulnerable population.

Also as regards the external surfaces of the buildings, including the roofs, it is necessary to consider evaluating the characteristics of roughness, absorption and reflection in the choice of the various materials, to avoid the formation of heat islands mainly due to a diffuse or speculate. Therefore, the interventions must aim to solve this problem by reducing these surfaces, using materials with a high albedo and modulating the spatial configuration to create greater shading solutions.

These adaptation actions and the need for detailed risk assessments for the elderly related to heat within the city are of primary importance to minimize the negative health effects associated with the significant and progressive temperature increases already observed in many cities in because of climate change and urbanization. Future research developments will be as follows. We intend to use the so-called big data from information shared on the internet to verify the relationship between a decrease in well-being and extreme thermoclimatic conditions. We also plan to evaluate the effect of climate change on the capability to live in a safe urban environment using the General Climate Models of the scenarios identified by the International Panel on Climate Change.

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Towards sustainable and inclusive communities: an integrated approach to assess sustainability in rural areas

Sustainable development is a priority in EU rural development strategies. Due to the multidimensionality of the sustainability issue, this paper presents a Spatial Decision Support System to assess territorial sustainability and help decision-makers in rural planning process. Four globally valid sustainability dimensions were considered (long-term ecological sustainability, satisfaction of basic human needs, promotion of intragenerational and intergenerational equity), measured by a set of socio-cultural-political-environmental indicators by using the Mazziotta and Pareto method.
The results of the S-DSS, implemented and verified in Basilicata region (southern Italy), provide the maps of sustainability values for each dimension at municipalities level, showing the usefulness of the tool to identify and monitor rural areas that require priority interventions and resources, in order to foster sustainable rural development.

1. Introduction

"If you don't know where you're going, you end up somewhere else." (Yogi Berra)

In this historical phase, the severity of some social costs, the excessive use of natural resources and the spread of pollution, have led to redefine community preferences and needs, paying attention not only to economic growth but also to social development and environmental protection with a view to sustainability (Böhringer and Jochem, 2007; Hàk et al., 2016; Salvati and Carlucci, 2014).

The concept of sustainable development was launched with the publication *Our Common Future*, commonly known as the Brundtland Report (WCED, 1987). Three decades passed since its definition, and achieving sustainable development is still a priority in the international and national agendas (Viccaro and Caniani,

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2019). However, sustainability is a really complex issue, as well as its assessment, and it is widely believed that public institutions cannot develop a strategy for sustainable development without a quantitative knowledge of overarching goals to reach and the state of the "system" in order to measure progress toward them (Costanza et al., 2016; Ronchi et al., 2002). In 2015, all UN Member States adopted the 17 Sustainable Development Goals (SDGs), representing a universal call to reach socio-economic and environmental sustainability by 2030. To that, the United Nations Statistical Commission established the Inter-Agency Expert Group on SDGs to identify a shared statistical information framework, based on a set of over 200 indicators, as a tool for monitoring and evaluating progress towards the SDGs.

Since that, multiple initiatives have helped to advance the "science of sustainability measurement", developing new indicators and models to help decision-makers in sustainable development policies at different scales. In particular, great progress has been made in the use of sustainability indicators at the national level and, while authors highlight the necessity to develop indicators of planetary sustainability (Costanza et al., 2016; Dahl, 2012; Holden et al., 2014), new approaches have been applied for integrating (and measuring) sustainability into regional development policy and planning (Boggia and Cortina 2010; Boggia et al., 2014, 2018; Ferretti et al., 2020; Palmisano et al., 2016; Paolotti et al., 2019; Péti, 2012; Salvati and Carlucci, 2014; Zolin et al., 2017). In Europe, these new approaches are stimulated by the European development idea of 'territorial cohesion'. Camagni (EEA, 2010, p. 43) claims that "*territorial cohesion has been defined as being the spatial representation of sustainability (which is time-oriented), since both territorial cohesion and sustainability represent an integration of people, planet and profit*". Territorial cohesion represents an opportunity to capitalise on the strengths of each territory so they can best contribute to the sustainable and balanced development of the EU.

In this context, promoting rural development is fundamental for the European Union: as pointed out in the Cork 2.0 declaration "*rural areas and communities play a key role in the implementation of the SDGs*" (EU, 2016) and it is, therefore, important to maintain high levels of life satisfaction in rural areas, as an indispensable condition to foster sustainable development (Boggia and Cortina, 2010; Ravetz, 2000). For a better application of programmes regarding rural development, such as the Rural Development Programmes (RDPs), it is very important to analyse and understand local opportunities and territorial characteristics. In this way, it is possible to guide and manage rural development. Different studies have largely demonstrated that RDP expenditure tends to be concentrated more on richer regions (or municipalities) than on ones that are lagging behind, causing territorial imbalances (Camaioni et al., 2019; Kiryluk-Dryjska et al., 2020). So, assessing the level of rural sustainable development in specific areas and finding explanations for the different levels is important in rural planning processes in order to increase the efficiency of rural development expenditures. This can help to maintain and improve both the level of development and the level of sustainability in rural areas (Boggia et al., 2014).

However, measuring sustainability in rural areas is not easy: rural areas present very different elements contributing to sustainable development (different environments, economic activities, social and cultural traditions), a concept in itself already complex. Thus, developing decision support systems based on spatial analysis of composite indicators is necessary to explore latent spatial patterns and trends of the main factors affecting sustainability in rural areas, providing an objective procedure able to estimate the importance of different drivers of sustainable development (Salvati and Carlucci, 2014). As pointed out by Palmisano et al. (2016), the integration of a Decision Support Systems (DSS) and of a Geographic Information System (GIS), known as Spatial Decision Support Systems (S-DSS), can provide different benefits in spatial planning processes, such as (i) the possibility to structure and evaluate the decision problem based on multiple evaluation criteria that have quantitative priority according to a specific decision rule, (ii) classify a series of alternatives based on their relative importance in meeting the analysis objective and (iii) identify the rural sustainable development potentialities of rural municipalities. Lastly, by the use of GIS, an S-DSS helps the parties to reach consensus in some types of conflicts by using a visual language that is easily explained and understood (Jelokhani-Niaraki and Malczewski, 2015).

Therefore, in the search for the "integrated and dynamic vision" of sustainability, the objective of the proposed study is to develop an S-DSS able to monitor rural sustainable development at a local scale. The model was build going beyond the popular ''triple bottom line'' model focusing on the balance between environmental, social, and economic issues (Holden et al., 2014). Starting from the Brundtland report and SDGs of 2030 Agenda, four key dimensions globally valid were identified to measure the sustainability (Holdel et al., 2014; Viccaro and Caniani, 2019), modelling a set of indicators according to the socio-cultural-political-environmental context (Casini et al., 2019; Péti, 2012) by applying the non-compensatory method proposed by Mazziotta and Pareto (De Muro et al., 2011). The Basilicata region was chosen as a case study, a rural region in Southern Italy. The analysis was carried out at the municipality level, sharing the idea that sustainable development could be achievable if it originates at the local level (Ferretti et al., 2020) and also to assess sub-regional disparities. A reduction in local disparities may favour an increase in regional performance compared to other regions (and to the national context). Confirming this, Lukovics (2008) points out that regional disparities are widening because the growth of the more developed sub-regions is increasing while the less favoured sub-regions are lagging behind. Consequently, rural analyses must devote increasing attention to the study of sub-regions. The results of the analysis will offer some reflections and discussion on the possible future developments of the planning tools.

The paper has the following structure: after a brief overview of the state of the art and of the contribution of our paper in growing the research on sustainability assessment (Section 2), the study area and materials and methods are presented in Section 3. The main results are discussed in Section 4 and concluding remarks, as well as discussion about future developments, are presented in Section 5.

2. Sustainability assessment: a brief overview and a step forward

As sustainability is a multidimensional concept, the appropriate instrument for analysing it according to a multidimensional representation is a suitable set of indicators that must be an integral part of an assessment methodology (Paolotti et al., 2019). The purpose of indicators is to provide a tool for guidance in sustainability policies, including monitoring of measures and their results, and communication to the public at large (Spangenberg et al., 2002).

Sustainability indicators generally differ in their characters, scales and ranges, and are usually aggregated into composite indexes of sustainable development mainly used at a global or national scale. In Italy, for example, the National Institute of Statistics (ISTAT) is engaged in the production of statistical measures for monitoring progress towards SDGs, based on the indicators defined by the UN Expert Group together with some specific national context data (ISTAT, 2019e). They represented the inputs for the definition of the Italian Sustainable Development Strategy, presented to the Council of Ministers in October 2017. All UN member States go in the same direction to evaluate their own progress towards sustainability. Global indexes are instead used to understand where the overall society is going, motivating and guiding the process of global societal change. Examples are reported in Costanza et al. (2016) and Holden et al. (2014).

However, the evaluation cannot be solely at a national level, although it is perhaps the most significant one and the most applied in international fora. Boggia et al. (2018) and Paolotti et al. (2019) evaluated regional sustainable development and its disparity among regions in three EU Member States (Malta, Spain and Italy), in order to support EU regional policy strategies. These studies have shown that, even within a small geographic area, spatial differences at regional levels identify the need for sustainability strategies that are not homogenous across a single territory at a national scale and that, therefore, sustainability assessment at a local scale is fundamental. Examples of studies conducted at municipality level are reported in Boggia et al. (2010) and Salvati and Carlucci et al. (2014), with a focus on rural areas in Boggia et al. (2014), Palmisano et al. (2016), Zolin et al. (2017), and more recently in Ferretti et al. (2020).

The common denominator of the studies conducted at a local scale mentioned above is the use of Multiple Criteria Decision Aiding (MCDA) techniques integrated with Geographic Information System (GIS). Known as Multiple Criteria Spatial Decision Support Systems (MC-SDSS), this integration has widely been used in many research fields over the last twenty years (Malczewski, 2006), such as agriculture (Riccioli et al., 2019), bioenergy (Romano et al. 2013), wildlife management (Cozzi et al., 2015b, 2019), rural evaluation (Cozzi et al., 2015a), wastewater management (Viccaro et al., 2017) and so on. MC-SDSS link concepts and methods of GIS and MCDA, providing new ways to face decision problems (Malczewski and Rinner, 2015) and, since spatial decision problems in rural development require a large number of alternatives to be evaluated based on multiple criteria, MC-SDSS represents the most suitable tool to evaluate a multidimensional concept like sustainable development. The methodology appears consolidated so much that it was proposed in form of plugin "GEOUmbriaSUITE" (Boggia et al. 2014; Palmisano et al., 2016; Paolotti et al., 2019) working in the open-source GIS software QuantumGIS (QGIS.org, 2020).

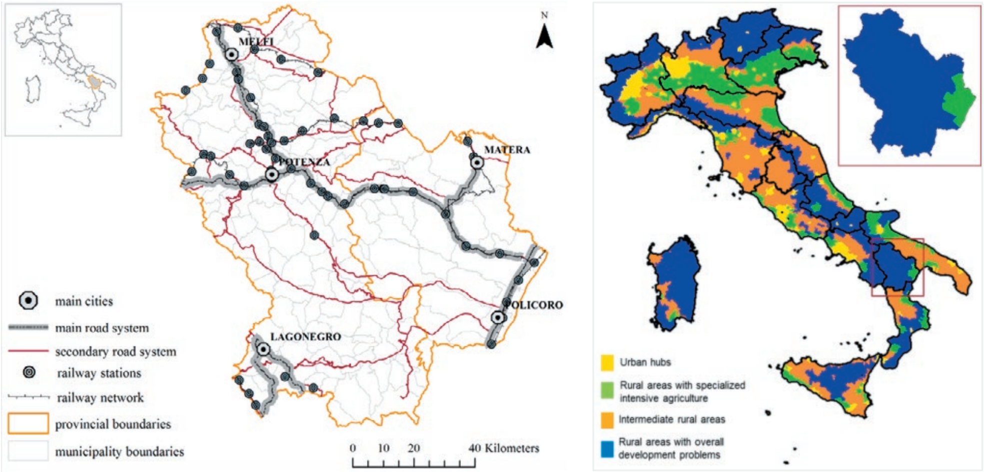
Despite progress in sustainability measure, with our work, we want to highlight two fundamental aspects underlying the concept of sustainable development not considered in the mentioned studies. To date, sustainable development has been evaluated according to the 'triple bottom line' (TBL) concept, originally served as an accounting framework that included environmental and social dimensions within the conventional finance-centric business performance model (Elkington, 1994). However, Holden et al. (2014), in the paper "Sustainable development: Our Common Future revisited", underline the necessity to reconsider the dimensions of sustainable development returning to its original definition used in the Brundtland Report, suggesting four primary dimensions: (i) safeguarding long-term ecological sustainability, (ii) satisfying basic needs, and promoting (iii) intragenerational and (iv) intergenerational equity. They argue that "*economic growth is a potential means to facilitate the fulfilment of the four primary dimensions and not a primary dimension in its own right*" (Holden et al, 2014: p.131). Moreover, the authors highlight that the proposed dimensions are all equally important and non-negotiable, what Daly (2007, p. 47) refers to as "*fundamental objective values, not subjective individual preferences*." Based on that, we argue that, in defining composite indexes for the sustainability dimensions, also the indicators used should be all equally important. So, the decision rules based on compensatory methods, used in the proposed MC-SDSS, appear inadequate. The above considerations represent the novelty of our work, "a step forward" towards sustainability assessment at a local scale.

3. Materials and method

3.1 Study area

The empirical analysis focuses on the Basilicata region (NUTS II) (Fig. 1a), one of the twenty regions of Italy, located in the south of the country (40° 30′ 1′′ North, 16° 6′ 50′′ East). The study area is characterized by a high geomorphological diversity (46.8% of the area is mountainous, 45.2% is hilly and only 8% is flat) and a wide altitude range, between 0 and 2,267 m a.s.l. With an area of 9,992 km^2, the Basilicata region is divided into two administrative provinces and 131 municipalities: two main hubs (Potenza and Matera) and a high diffusion of small rural municipalities (with less than 2,000 residents, which affect the 48% of the total number), with limited population density (61 inhabitants per km^2) compared to the rest of Italy and Europe. The study area, disadvantaged by its morphological constitution and largely devoid of important communication routes, is one of the regions with the greatest delay in the development of the country, which is associated with all the problems related to depopulation and population ageing. Indeed, the study area is identified in the EU programming as a predominantly rural territory (OECD, 2010), so that rural development programs concern substantially the whole area (National rural network 2014-2020) (Fig. 1b). The agri-food sector plays an important role in the regional economy (Viccaro et al., 2018). According to the latest data of the agricultural census (ISTAT, 2019b), the percentage of employed in agriculture equal to 8.36%, is above the data of the comparative divisions: South = 6.73%; Italy = 3.90%; EU 27 = 4.6%, confirming the strong ag-

Figure 1. Maps of the study area: Basilicata region (a) and National rural network 2014-2020 (b).



a) Basilicata region

b) National rural network 2014-2020

ricultural and rural character of the region. A significant component that reflects the marked natural and rural character of the study area is represented also by the tourism sector, a progressive growth sector; however, it suffers the distance from the main metropolitan areas.

3.2 Theoretical framework

The theoretical structure that defines the concept of sustainability in our study is based on four key dimensions: 1) long-term ecological sustainability, 2) satisfaction of basic human needs, 3) promotion of intragenerational equity and 4) promotion of intergenerational equity.

The four dimensions, closely connected with the SDGs, can be described as follows:

- Long-Term Ecological Sustainability (LTES): *"At a minimum, sustainable development must not endanger the natural systems that support life on Earth: the atmosphere, the waters, the soils, and the living beings"* (WCED, 1987, p. 44). Therefore, it measures the main elements of pressure on natural capital assets, such as water, air, soil, vegetation. In particular, (a) the water consumption (SDG 6), (b) the soil consumption (SDG 11), (c) the protection of natural and semi-natural ecosystems and biodiversity (SDG 15) and (d) the incidence of pollutants in the atmosphere for the fight against climate change (SDG 9, SDG 13).
- Satisfaction of Basic Human Needs (SBHN): *"It [sustainable development] contains […] the concept of 'needs,' in particular the essential needs of the world's poor, to which overriding priority should be given"* (WCED, 1987, p. 43). In a developed society it measures the level of achievement of a series of basic elements, that is (a) the level of achievement of certain income standards and employment levels (SDG

1, SDG 2, SDG 8), (b) ensuring adequate conditions of health care (SDG 3), (c) providing quality education and learning opportunities for all (SDG 4) and (d) making adequate settlements and resilient communities (SDG 11).

- Promotion of Intragenerational Equity (PIntraE): the Brundtland report states that social equity between generations *"must logically be extended to equity within each generation"* (WCED, 1987, p. 43). Therefore, it measures intra-generational inequalities in the (a) distribution of wealth (SDG 10), (b) in education (SDG 4), (c) in work (SDG 8). In addition, great importance was given to (d) monitoring gender equality in work and politics (SDG 5).
- Promotion of Intergenerational Equity (PInterE): *"We act as we do because we can get away with it: future generations do not vote; they have no political or financial power; they cannot challenge our decisions"* (WCED, 1987, p. 8). Therefore, it measures the sustainability of land development through (a) the level of sustainable forest management (SDG 15), (b) monitoring the sustainable use of water resources (SDG 6), (c) the possibility of making cities and human settlements sustainable, favouring the reuse of waste (SDG 12) and the use of renewable energy sources, preserving the cultural and natural heritage (e.g. fires) (SDG 7, SDG 11, SDG 13, SDG 15) (WCED, 1987, p. 8).

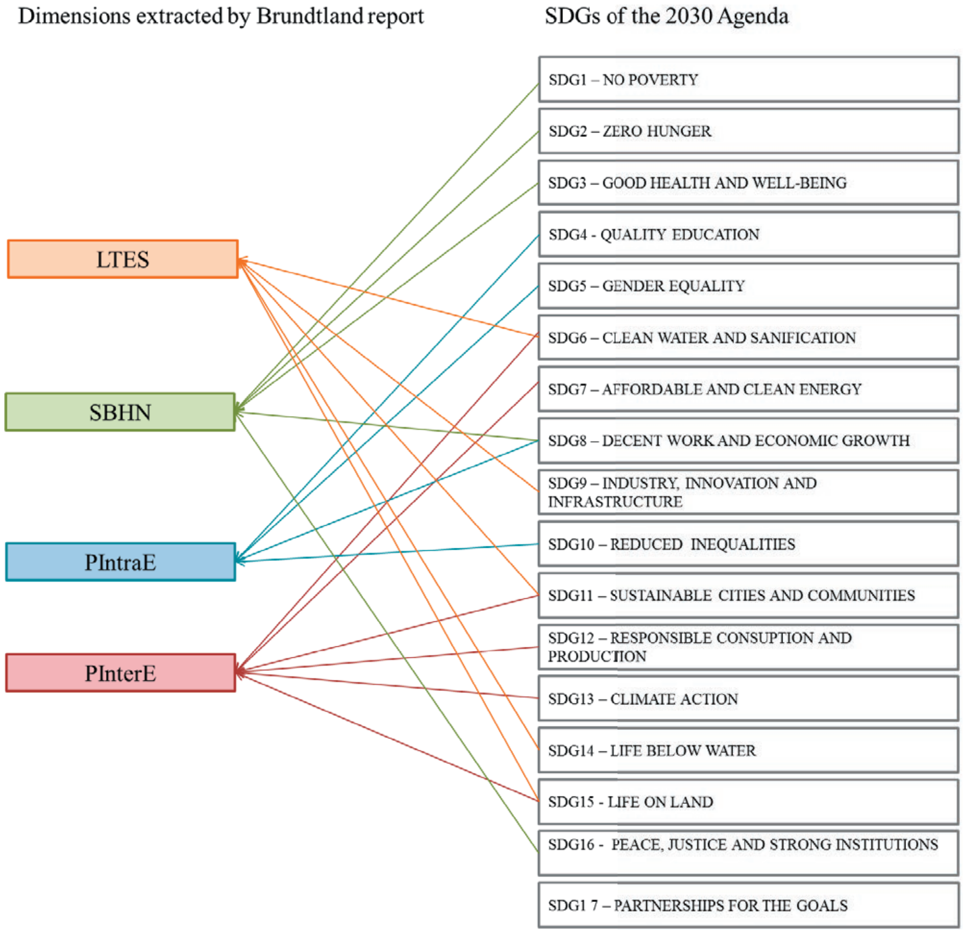
This structuring departs from the popular triple bottom line model, focused on the balance between environmental, social and economic issues (Elkington, 1994), which currently dominates politics and to some extent the academic debate on sustainable development (Ferretti et al., 2020; Rogers et al., 2008; UN, 2012).

In the following scheme, it is possible to highlight how the SDGs are placed within each dimension. Some goals can also fit into multiple dimensions (see Fig. 2).

3.3 Identification and selection of elementary indicators

The study of literature (Ferretti et al., 2020; Lior et al., 2018; Salvati and Carlucci, 2014) and the regulatory framework on the topic, led to identify a set of indicators representing the four key dimensions of sustainability (Table 1). The indicators capable of guaranteeing, analytical stability, measurability, territorial and temporal coverage have been selected (Maggino, 2014; OECD, 1993). The set of indicators was also chosen according to the context, focusing our attention on the indicators which, as regards rural areas, proved to be relevant for highlighting sub-regional differentials, or relative sustainability, which is the specific object of our analysis (Casini et al., 2019). For the analysis, different sources were used to collect data at the municipality level. The principal source was the Italian National Institute for Statistics. Statistics were also collected from GSE, INEMAR, ACI, Ministry of the Interior, ISPRA, Ministry of the Environment and Protection of the Territory and the Sea, etc. In some cases, proxy variables to compensate for the lack of data and spatial analyses in the GIS environment (e.g. the hospital facilities accessibility and quality - SBHN3, see Table 1) were used. The indicators were analysed through descriptive statistics and Pearson correlation analysis (Dowdy et al., 1983), to evaluate the presence of correlation (cause-effect relationships) and to screen the polarity with respect to the objective. For direct correlation (and

Figure 2. Relationship between dimensions and SDGs.



similarly for the inverse one), we distinguish a weak correlation for the interval $0 < \rho_{x,y} < 0.3$, a moderate correlation for the interval $0.3 < \rho_{x,y} < 0.7$ and a strong correlation for $\rho_{x,y} > 0.7$.

The preliminary study led to identify 24 indicators, 6 for each dimension (see Table 1). The selected indicators refer to a variable period between 2011 and 2018 depending on data availability. The temporal range could be considered acceptable since the growth process at a local scale in very low.

3.4 Integrated evaluation of the indicators

The choice of aggregating elementary indicators into composite indicators (or indexes) stems from the need to have synthetic information with respect to com-

Table 1. Dimensions and indicators used in the case study, meanings and sources.

Dimension/Indicator	Description	Reference unit	Source and reference year
Long-Term Ecological Sustainability (LTES)			
LTES1 – Greenhouse-gas emissions from productive activities	Greenhouse gas emission coefficients (represented by GHRO) per Annual Labour Unit (ALU) for the different productive activities in the national context have been estimated, starting from National Accounts Matrix including Environmental Accounts, subsequently multiplied by the ALU of the productive activities in each municipality	TonCO_2eq	ISTAT (2011)
LTES2 - Water consumption	Water introduced into municipal drinking water distribution systems	Thousands of cubic meters per inhabitant	ISTAT (2015)
LTES3 - Soil consumption	Variation from 1989 to 2017 of the percentage ratios between artificial areas and municipal areas	%	School of Engineering - Unibas (2017)
LTES4 – Potential greenhouse-gas emissions from vehicles	Potential greenhouse-gas emissions from vehicles have been estimated by multiplying vehicle fleet with an emission factor according to the category, related to the population aged 18-80 years for each municipality	kgCO2eq/km per capita (18-80 years)	ACI (2017) and -INEMAR (2014)
LTES5 - Incidence of protected areas	Percentage ratio between protected areas (Official List of Protected Areas and the Natura 2000 network) and municipal area	%	Ministry of the Environment and Protection of the Territory and the Sea (2018)
LTES6 – Incidence of organic agriculture	Percentage variation between organic UAA[1] 2018/UAA 2010 and organic UAA 2010/UAA 2010	%	Istat (2010); and Phytosanitary office of Basilicata Region (2018)
Satisfaction of Basic Human Needs (SBHN)			
SBHN1 - Average per capita income	Data relating to the declarations on the taxable income of individuals for the additional personal income tax	Euro	Ministry of Economy and Finance (MEF) (2017)

Dimension/Indicator	Description	Reference unit	Source and reference year
SBHN2 - Employment rate	Percentage ratio between employed people aged 15 and over and the resident population aged 15 and over	%	Urbistat (2017)
SBHN3 - Hospital facilities accessibility and quality	Evaluation of the hospital service quality (beds, number of departments, equipment), weighted according to the time needed to reach the facility using the isochronous method by Network Analysis (Wang et al., 2012)	Adimensional (range 0-6.50)	Regional technical map (2013), and Ministry of Health (2013)
SBHN4 - High schools' accessibility and differentiation	Evaluation high schools offer, normalized based on the time to reach the structure from each municipality	Adimensional (range 0-10)	Regional technical map (2013)
SBHN5 - Quality of housing	Average of basic services available in the home[2] and buildings in good condition[3]	Adimensional (range 0-1)	ISTAT (2011)
SBHN6 - Social and material vulnerability index	Aggregation of: 1) percentage of 25-64-year-old illiterate and literate population with no educational qualification; 2) percentage incidence of families with potential economic hardship; 3) percentage incidence of families with potential care difficulties; 4) percentage incidence of the population in serious crowding; 5) percentage incidence of families with 6 and more members; 6) percentage incidence of young and adult single-parent families; 7) percentage incidence of non-active 15-29-year-olds and non-students[4]	Adimensional (70-130)	ISTAT (2011)
Promotion of Intragenerational Equity (PIntraE)			
PIntraE1 - Income inequality index	Gini concentration index to measure inequality in income distribution	(range 0-1)	MEF (2017)
PIntraE2 - Unemployment rate	Percentage ratio between the resident population aged 15 and overlooking for employment and resident population aged 15 and over	%	Urbistat (2017)

Dimension/Indicator	Description	Reference unit	Source and reference year
PIntraE3 - Incidence of adults with diplomas or degrees	Percentage ratio between the resident population aged 25-64 with a high school diploma or university degree and the resident population aged 25-64	%	ISTAT (2011)
PIntraE4 - Gender inequality in the labour market	The ratio between the male employment rate and the female employment rate	Adimensional (range 0-3)	ISTAT (2011)
PIntraE5 - Women and political representation at the local level	Percentage ratio between elected women and the total elected officials in municipal administrations	%	Ministry of the Interior (2018)
PIntraE6 - Employment turnover index	Percentage ratio between those aged 45 and over and those aged 15-29	%	ISTAT (2011)
Promotion of Intergenerational Equity (PInterE)			
PInterE1 – Incidence of sustainable forest management	Percentage ratio between managed wooded forest area and total forest area	%	Forest management plans (2018)
PInterE2 - Dispersion of water from the distribution system	Total water losses in municipal drinking water distribution systems (percentage value on the total volume introduced into the system) (mc)	%	ISTAT (2015)
PInterE3 - Separate collection of municipal waste	Percentage of municipal waste subject to separate collection out of the total amount of municipal waste collected	%	ISPRA (2018)
PInterE4 - Production of energy from renewable energy sources	Production of energy (electric and thermal installed power) from renewable sources (MW) compared to the population	MW per capita	Energy Services Operator (GSE) (2018)
PInterE5 - Public expenditure for the protection and enhancement of cultural goods and activities	Municipal public expenditure for the protection and enhancement of cultural goods and activities concerning total expenditure	%	Ministry of the Interior (2015-2017)
PInterE6 - Impact of forest fires	Percentage ratio between forest area covered by fire and total forest area	%	Ex-State Corps of Foresters(2011-2013)

[1] Utilised Agricultural Area (UAA).
[2] Internal drinking water services, b) internal toilet, c) bath or shower and hot water.
[3] Physical conditions, both internal and external, in "excellent or good" state of conservation.
[4] http://ottomilacensus.istat.it/fileadmin/download/Indice_di_vulnerabilit%C3%A0_sociale_e_materiale.pdf

plex realities, expressed in ways that are easily understood by a large number of people and to promote an integrated approach in the decision-making process. Several authors (e.g. Boggia et al., 2014; Ding et al., 2014; Liu, 2007; Paolotti et al., 2019) have proposed integrated methodologies for assessing and monitoring sustainability, in order to help decision-makers.

Therefore, to allow an integrated assessment of the dimensions considered, measured operationally by the selected indicators, different aggregation methods were studied. There are several classification schemes for aggregation methods. They include those based on the semantics of the aggregation (Beliakov et al., 2007; Grabisch et al., 2009) and those based on the authorization degree of the compensation (OECD, 2008). In particular, according to the latter scheme, the most widely used aggregation methods include additive aggregation methods (e.g. arithmetic mean), multiplicative aggregation methods (e.g. geometric mean) and non-compensatory aggregation methods (e.g. multicriteria analysis).

In the specific case, assuming that the elementary indicators cannot be replaced with each other, attention was paid to non-compensatory aggregation methods (Mazziotta and Pareto, 2016, 2018). We have chosen the method of penalty for variation coefficient, proposed by Mazziotta and Pareto (De Muro et al., 2011). It is a non-compensatory method, which allows the construction of a synthetic measure for each territorial unit (x_i). This method was also chosen because it is applicable in the presence of null values; moreover, compared to methods based on geometric mean (Diewert, 1995) this method is more robust and not very sensitive to the elimination of a single elementary indicator.

The method provides for the standardization of the indicators by means of a transformation criterion that frees them both from the unit of measurement and their variability (Delvecchio, 1995). Therefore, the elementary indicators have been re-proportioned, in such a way as to oscillate all within the same standardized scale, with an average 100 and an average square deviation 10: the values obtained are included in a range (70-130).

Given the matrix $X=\{x_{ij}\}$ of n rows (territorial units) and m columns (elementary indicators), it is possible to calculate the normalized matrix $Z=\{z_{ij}\}$ in the following way:

$$z_{ij} = 100 \pm \frac{\left(x_{ij} - M_{x_j}\right)}{S_{x_j}} 10 \quad (1)$$

where $M_{x_j} = \frac{\sum_{i=1}^{n} x_{ij}}{n}$ and $S_{x_j} = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{ij} - M_{x_j}\right)^2}{n}}$ are, respectively, the mean and the standard deviation of the j indicator, while the ± sign represents its polarity.

Indicating with M_{Zi}, S_{Zi} and cv_{Zi}, respectively, the mean, the standard deviation and the variation coefficient of the normalized values for the statistical unit i, the composite index of Mazziotta and Pareto (MPI, Mazziotta and Pareto Index) is defined as follows:

$$MPI_i^{\pm} = M_{z_i} \pm S_{z_i} cv_{z_i} \quad (2)$$

The arithmetic mean of the normalized indicators is therefore corrected by a quantity (the product $S_{Zi}cv_{Zi}$) proportional to the mean square deviation and a direct function of the coefficient of variation. This variability, measured through the coefficient of variation (cv_{Zi}), makes it possible to penalize the score of the units which present a greater imbalance between the values of indicators. The use of normalized standard deviation (S_{Zi}) allows to build a robust measure that is not very sensitive to the elimination of a single elementary indicator (Mazziotta et al., 2010).

Ultimately, if the regional average represents the reference value, we are able to make relative comparisons between the different municipalities and evaluate the degree and the distribution of sub-regional disparities for each dimension.

4. Results and discussion

The application of methodology (as described in the Section 3) allowed us to obtain a map for each dimension. Figure 3 shows municipalities in advantage conditions (value of MPI>105) and municipalities in disadvantaged conditions (value of MPI<95) compared to the average (regional) value (95≤MPI≤105), respectively represented in shades of green and red. First of all, a greater negative imbalance for all dimensions was detected.

More in detail, advantaged clusters were identified for the SBHN and PIntraE dimensions in the crown areas of large urban centres and commercial attractions (see Fig. 3b, c). In these areas, however, worse ecological sustainability (LTES) insists (see Fig. 3a): this is due to a) greater concentration of productive activities and/or the presence of point sources[1] with high emissions (LTES1); b) higher water consumption (LTES2) (the central-eastern portion of Basilicata, the Val D'Agri area); c) higher land consumption (LTES3) linked to urban fragmentation processes (e.g. municipality of Potenza), which is quite high for the study area (88% compared to a national average of 84%) (Saganeiti et al., 2018). It is, indeed, a phenomenon of considerable importance due to the progressive abandonment, depopulation and disuse of historic city centres in favour of new land consumption in peripheral and peri-urban areas. This affects ordinary urban management: higher energy costs both in the public and private sectors, heavy technical-economic-organizational commitments in any kind of services provision (due to the distances among residential areas and the very low population density of the same) with consequences also on the quality of landscapes and ecosystems.

Large disadvantaged clusters were observed for the SBHN dimension in the central (on the border between the two provinces) and in the south part of the study area (see Fig. 3b). In these areas, in addition to lower incomes (SBHN1) and lower employment (SBHN2), lower quality of housing (SBHN5) was found. Indeed, 3.1% of the population lives in houses without basic services (compared to

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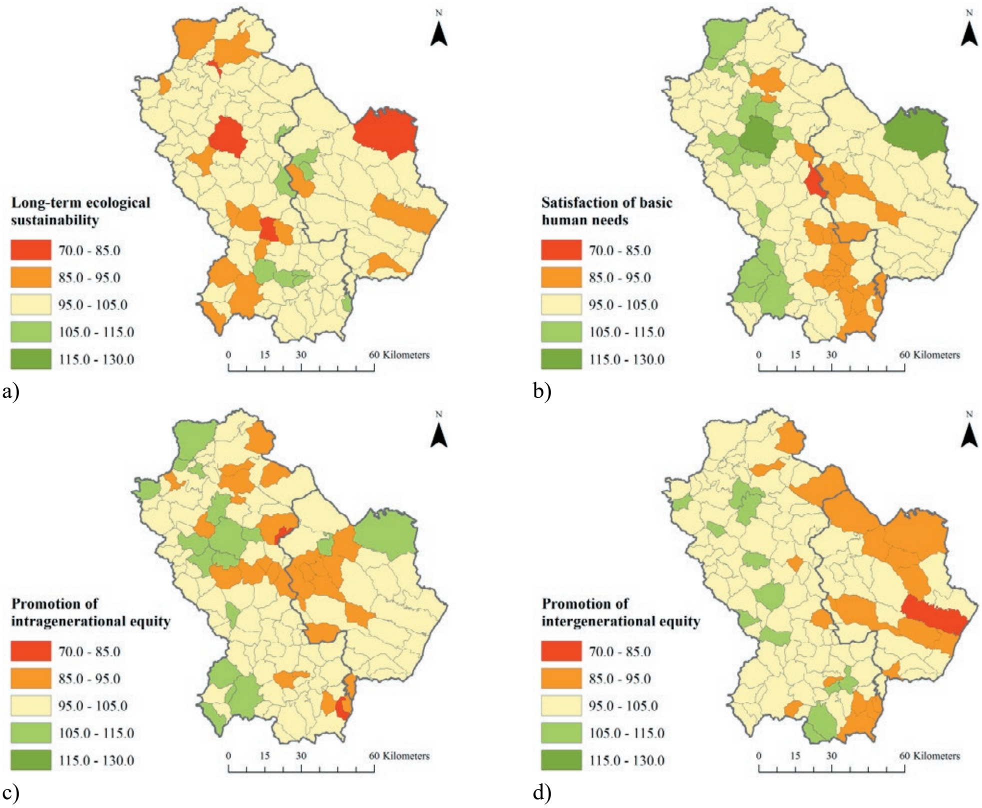
[1] Twenty-point sources were detected within the Atmospheric Emissions Inventory of 2015 produced by the Basilicata Environmental Observatory Foundation - FARBAS.

Figure 3. Sustainability indices for the four dimensions: a) Long-term ecological sustainability (LTES), b) Satisfaction of Basic Human Needs (SBHN), c) Promotion of Intragenerational Equity (PIntraE), d) Promotion of Intergenerational Equity (PInterE).



a regional average of 1.6%) and 35.3% of the population lives in poor condition buildings (compared to a regional average of 23.1%). Added to also lower accessibility to hospitals (SBHN3) and secondary schools (SBHN4) (journey times > 60 minutes) was found.

The PIntraE dimension is characterized by a condition generally falling within the average, with clusters both above and below the average (see Fig. 3c). The disadvantages clusters are concentrated in the central portion of the study area. This is mainly due to a lower education rate (diploma or degree) (PIntraE3) and a greater inequality in the distribution of income among the population (PIntraE1). Overall, the recent dynamics, despite an employment improvement in the study area, do not allow to prefigure a territorial balance of the labour market, characterized by gender differentials (PIntraE4) (male-female ratio greater than 2:1) in many municipalities of the Matera province and a generalized low employment turnover (PIntra6). The female representation in politics at a local level (PIntraE5), following the law 23 November 2012 n. 215, has doubled (from 14% to 28% in the period 2001-2018), but is still below the Gender balance zone (percentage between 40% and 60%) (EIGE, 2016).

Within the PInterE dimension, few virtuous municipalities above the average, scattered in the province of Potenza, were observed (see Fig. 3d). They are mainly characterized by sustainable forest management (PInterE1)[2], more sustainable waste management (PInterE3) and higher production of energy from renewable sources (PInterE4). The negative values are concentrated mainly in the province of Matera, mainly linked to the impact of forest fires (PInterE6) (being these areas more vulnerable); they constitute one of the main factors of environmental change in a wide range of agricultural and forest ecosystems (FAO, 2007). A second cluster of negative values is concentrated in the south-east of the study area, mainly linked to management shortcomings, including the management of water resources (PInterE2) and urban waste (PInterE3). Actually, the water dispersion from distribution system (attributable to breakages in pipes, pipelines or fittings, obsolescence of materials), represents a generalized problem in the region, going from 32.7% in 2012 to 55.9% in 2015 (92 municipalities with losses greater than 50% compared to the national average of 41.4%). As regards the waste collection, from 2010 to 2017, a marked increase in the percentage of separate collection was found, going from 10.7% to 41.7% (compared to the Italian average of 55.5%). During this period, many municipalities in the province of Matera took action for more sustainable waste management. It affected positively a form of aggregate management among municipalities, that allowed waste separate collection percentages above 65%. Indeed, often the scarce local autonomy (lower spending capacity) in such contexts determines the inability of self-regulation with respect to intergenerational equity (sustainable forms of management, such as separate waste collection, water loss control and management of local resources). This denotes how the Union among municipalities (Legislative Decree No. 267 of 2000) could represent also a virtuous attempt towards new ways of self-regulation of sustainable development at a local level.

In general, a low interaction was detected among the four dimensions. However, by analysing the relationships among them, a (weak) negative correlation between the LTES and SBHN dimensions (64% - 84 out of 131 municipalities appears to have an imbalance between the two dimensions) was found. This means that the study area is positioned in the growing portion of the environmental Kuznets curve, which has an inverted U shape (Hanley et al., 2001). This position is typical of developing economies, where an increase in economic well-being implies an increase in environmental pressure. Indeed, only in few municipalities (9% - 12 out of 131 municipalities), better economic well-being is accompanied by better ecological sustainability. To move towards the decreasing part of the environmental Kuznetz curve, typical of mature economies, it would be necessary an increase in

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[2] The percentage of managed forest area is increased in the last 20 years (55 plans drawn up in 2006-2015); however, many of the plans drawn up in the past have expired, so as of 2018 there is again a contraction of the actively managed area.

the elasticity of demanded environmental goods quantity with respect to income, and an increase in the capacity of policymakers to accept and incorporate stakeholder's opinions in the choices, encouraging technological innovation and structural changes.

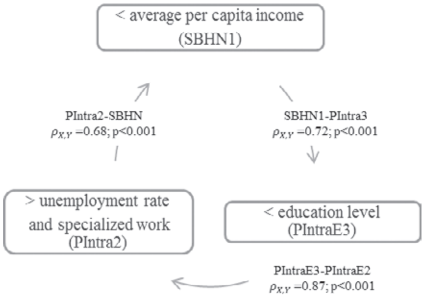
The remaining share of municipalities (27% – 35 out of 131 municipalities) is characterized both from low LTES and SBHN values. An example of this relationship is the greater potential greenhouse gas emissions from vehicles in areas with less access to essential services and/or without the railway network (in the south of the study area). This can be confirmed by lower mobility rates by public transport (less than 10%) respect to the areas covered by the railway network (between 18% and 27%) (ISTAT, 2019a). A negative self-reinforcement process was generated, i.e. an increase in private mobility due to a progressive contraction of public transport, which was itself determined by a contraction of users. This led to an increase in potential greenhouse gas emissions from vehicles (LTES4) from 2002 to 2017 despite a reduction in the population aged 18-80 years. In this sense, as also underlined by Ferretti et al. (2020), public intervention is needed to generate better infrastructure, extend the railway or upgrade public transport systems at peak times, bearing in mind that the creation of new transport infrastructure or the strengthening of existing infrastructure must not cause environmental damage. Furthermore, very often the most marginal areas, which show negative growth dynamics, have natural resources (e.g. they are part of regional and national parks) not fully valorised. Thus, the results highlight the need of variables to facilitate the introduction of natural capital concepts into decision-making processes (Bernetti et al., 2013).

Another element of interest concerns a (moderate) positive relationship between SBHN and PIntraE dimensions; indeed, 75% of municipalities (98 out of 131 municipalities) had a negative or positive balance between the two dimensions; more precisely, a low SBHN level corresponded to a low PIntraE level for 44% of the municipalities (58 out of 131 municipalities). This result is in agreement with Wilkinson and Pickett (2009), who found that health and social problems - which prevent societies from meeting the basic needs of their inhabitants - are more common in countries with high levels of inequality. Furthermore, the relationship between high social and health problems and high levels of inequality is such that the latter causes the former. Therefore, reducing the level of inequality (thus increasing intra-generational equity) would consequently lead to an improvement in the ability of a community to meet the basic needs of its inhabitants.

Furthermore, our results show that a lower per capita income (SBHN1) led to a lower level of education (PIntraE3) ($\rho_{x,y}$=0.72, p<0,001) and therefore a higher unemployment rate and less specialized work. (PIntra2) ($\rho_{x,y}$=0.87, p<0,001), which consequently led to a lower per capita income (SBHN1) ($\rho_{x,y}$=0.68, p<0,001) (see Fig. 4). It triggered what the economist Nurske calls the vicious circle of poverty (Nurkse, 1971).

The relationship between development and education has been emphasized in a wide range of studies (Becker, 1994; Psachoropoulos and Patrinos, 2004). Amartya Sen, in her fundamental study Development as Freedom, argued that a gen-

Figure 4. Vicious circle of poverty.



eral expansion of education and literacy can facilitate social change and help to improve the economic progress that others also benefit from (Sen, 1999, p.129). Moreover, Liu et al. (1986) supported the hypothesis that investments in human resources, especially through the improvement of education (elementary and secondary), would enhance social mobility, which in turn would enhance the productivity of labour and capital. Therefore, it would be appropriate to act through redistributive policies and an increase in the quality of education.

5. Conclusions

The proposed approach to measuring territorial sustainability was structured through four independent dimensions derived from the global framework on sustainable development (according to a top-down approach), consisting of an integrated system of indicators adapted to the context (according to a bottom-up approach).

The results obtained allow us to read the distribution of the composite indicators (dimensions) on the territory and to analyse which components and/or correlations between components are the cause of the positive and/or negative phenomena.

To promote an integrated decision-making approach of sustainable development, it is necessary to foster a territorial balance in the territory for each of the four dimensions. However, the simultaneous improvement of all dimensions raises a complex problem on how we can reach a certain level for one dimension without simultaneously reducing the possibility of it being reached for another dimension. The key to solving this problem is to decouple existing unwanted correlations between negative dimensions and cause-effect relationships and promote positive ones; this is one of the challenges presented to decision-makers with this study.

More specifically, the larger (urban) municipalities are characterized by greater sustainability in terms of essential needs and intra-generation equity but also less ecological sustainability; however, the smaller and more rural municipalities (central and southern regions) are not only characterized by lower levels as regards the fulfilment of essential needs and intra-generational equity, but this also implies repercussions in the ecological sustainability and inter-generational equity.

Finally, the satisfaction of basic needs and the intragenerational equity, acting synergistically, generated clusters affected by the socio-economic exclusion.

The proposed framework represents, in the current political context, a useful support tool in identifying and monitoring the areas that require priority actions and resources, with a view to efficient resource management, and in promoting sectoral decision-making processes in a global strategy.

More specifically, in a rural context, this implies an overall rural development perspective that considers sustainability as an essential precondition for any possible development of these areas. Indeed, in many realities, rural development programmes focused on funding sectoral actions and did not partner with other structural funds and local resources.

This study represents a first step in developing tools helpful to monitor sustainable development at a local scale going beyond the "triple bottom line" approach. The strength of the proposed approach consists in the simplicity and transparency of the four dimensions, considered non-negotiable and equally important, based on the common definition of Sustainable Development. However, still much to be done. Future developments will be oriented towards improving the representativeness of indicators, choosing a set of standard indicators making the model replicable in other contexts, as well as the choice of the aggregation method. In fact, despite the method used in this study is a consolidate method in constructing composite indices, it gives a picture of the phenomena based on the mean values of indicators considered, but it does not allow to consider the distance from the "best solution" or "ideal point", that is usually required in evaluating some indicators (e.g. greenhouse gas emissions).

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Circular Economy and adaptive reuse of historical buildings: an analysis of the dynamics between real estate and accommodation facilities in the city of Naples (Italy)

The urban regeneration of historic centres is an extremely topical issue in the contemporary debate and is an essential prerequisite for the pursuit of Sustainable Development Goals. Adaptive reuse of the abandoned heritage represents an effective strategy to give new life to abandoned or underused portions of territory, hosting functions more suited to the needs of the contemporary city and its characterizing phenomena. This work is the result of an experimentation that has as object of investigation the historic centre of Naples where, according to some recent data, there has been a significant increase in Bed and Breakfasts, some often as result of cultural heritage reuse processes. After having spatially represented the market values of residential buildings through the elaboration of a Geographic Information System, it was possible to verify the existence of a relation between the dynamics of the real estate and the rise of new accommodation facilities, often located in historic buildings subjected to adaptive reuse processes.

1. Introduction

1.1 Cultural heritage adaptive reuse as a way to support urban regeneration

In 2015 the General Assembly of the United Nations adopted the 2030 Agenda for Sustainable Development which presents 17 Sustainable Development Goals (SDGs) and 169 targets in order to achieve a more equal, inclusive, sustainable, safe and prosperous future (United Nations, 2015).

In particular, the SDG number 11, i.e. "Make cities inclusive, safe, resilient and sustainable", regards sustainable cities and communities and highlights the interdependence between good urbanization and development (United Nations, 2017). It enhances also the linkages with other positive effects, such as job creation, livelihood opportunities and improved quality of life (UN Habitat, 2016).

Urban regeneration is a very relevant prerequisite for the SDGs achievement and regenerating means giving new life to portions of territory that are in a state of neglect or underutilization, determining the birth of new life cycles capable of restoring the right degree of attractiveness. As a matter of fact, cities are able to reinterpret their components in order to overcome a decline phase, giving rise to

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new functions and services. As stated by De Toro et al. (2020), urban development and regeneration projects can produce multidimensional impacts on the city, from an economic, cultural, social and environmental point of view. Furthermore, one of the main conditions of fragility in our urban centres is the state of degradation and abandonment of much of the built heritage and in particular of the historical buildings. This condition of under-use not only affects the aesthetic quality of the urban environment, but also represents a factor of disintegration, slowing down development possibilities and influencing people's lifestyle and the evolution of the local economy. Starting from the shared assumption that heritage with cultural significance can be seen as a form of multidimensional capital, then it is possible to understand the potentiality of this resource not only in terms of cultural and symbolic values but also in terms of an economic asset able to yield a flow of services over time, that in turn generate both economic and cultural values (Throsby, 2001). In this way, it is possible to determine a generative and regenerative process that can give life to important parts of the urban fabric, reactivating the relationships between these assets and the urban and social context in which they are integrated.

Sustainable urban regeneration takes into account many techniques and, with reference to cultural heritage, a very promising approach is known as "adaptive reuse" (Fitch, 1982; Douglas, 2006; Bullen and Love, 2011). Cultural heritage is considered a resource for local sustainable development (Conference of Ministers of Culture, 2018), although «there are some contradictions. The sites recognized as cultural heritage are increasing; the costs for functional maintenance/reuse are growing, while public resources available are becoming scarcer, and private actors are increasingly focused on the short time for payback. The consequence is that there is a growing risk that the decay of heritage increases year by year, because of lack of funding support» and viable business models (Fusco Girard and Gravagnuolo, 2017, p. 38).

For this reason, adaptive reuse can become a solution able to reduce many environmental impacts, such as Greenhouse Gas (GHG) emissions, extending the building's life span and avoiding the production of Construction and Demolition Waste (CDW), planning low carbon cities in order to face the problem of climate change (Yung and Chan, 2012). It is therefore clear that one of the most important tools is the adaptive reuse of urban voids and abandoned heritage assets in order to host functions more suited to the contemporary needs and the characterizing urban phenomena, in line with the principles of Circular Economy (CE) (EMF, 2017; Gravagnuolo et al., 2019). Adaptive reuse is defined as «any building work and intervention to change its capacity, function or performance to adjust, reuse or upgrade a building to suit new conditions or requirements» (Douglas, 2006, p. 1) and can be considered as a way to extend a building's function through its use for another purpose, avoiding to reach the end-of-life phase (Chan et al., 2020). Thus, the aim of adaptive reuse is that of preserving the architectural integrity of historic buildings, through a process of adaptation to the needs of a community (Elsorady, 2014). Definitely, through this process a disused or ineffective item can be reused for a different purpose (Department of Environment and Heritage, 2004), preserving in this way the heritage significance (Günçe and Mısırlısoy, 2019). According to Bullen and Love (2010), conservation can promote sustainability principles in its preventing irreversible loss of heritage, protecting environmental resources and promoting wide use of natural capital with both renewable and non-renewable resources. Adaptively reusing a building means not only reusing its functionality but also its single components and materials, preserving its embodied energy and thus reducing CO_2 emissions. Embodied energy represents the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site. Actually, constructing new buildings consumes raw materials and energy, generating, in addition, carbon emissions. More than 40% of global energy use and one third of global GHG Emissions is caused by buildings (UNEP, 2009), together with the production of million tonnes of CDW (HUD, 2003); the latter represents the largest waste stream in EU according to volume[1]. This is confirmed also for the Italian context, in which about 40% of the energy is used to heat, cool, illuminate and ventilate buildings (Di Turi and Stefanizzi, 2015). More specifically, «the buildings and construction sector accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO_2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement and glass» (Global Alliance for Buildings and Construction et al., 2019, p. 9).

Despite this huge environmental impacts, there are multiple opportunities to mitigate GHG emissions and to enhance and exploit the energy and emissions saving potential in buildings (UN Environment and International Energy Agency, 2017). For this reason, it is clearly understandable the potentiality that lie in the possibility of increasing the life of a building through adaptive reuse, in order to lower material, transport and energy consumption and pollution, contributing to face climate change and to meet the principles of sustainability with its multiple dimensions (Bullen and Love, 2010).

Adaptive reuse is advantageous not only from an environmental point of view, but also from a social and economic one (Gravagnuolo et al., 2017). Indeed, it is possible to preserve the *genius loci* (Norberg-Schulz, 1980, 1998; Fusco Girard and Vecco, 2019) of a certain historic area so that the inhabitants are still able to recognize themselves in that area and furthermore, restoring and maintaining the heritage significance of a building can prevent it from falling in disrepair, providing in the meantime new opportunities for the community. In addition, adaptive reuse of historic buildings can guarantee several financial savings and returns (Australian Government, 2004).

The implementation of the concept of adaptive reuse represents, therefore, «the link between the preservation of the past for its intrinsic value, and as a resource for the modern community as a commercial activity» (Ashworth and Tunbridge, 1990, p. 24), so that tourism and heritage are able to coexist in a synergistic and circular way and tourism revenues can be used to sustain environments of

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[1] European Commission (2018), EU Construction and Demolition Waste Protocol and Guidelines, www.ec.europa.eu/growth/content/eu-construction-and-demolition-waste-protocol-0_en.

heritage value, giving rise to a form of sustainable tourism, that must be economically viable, environmentally sensitive and culturally appropriated (Nasser, 2003).

This strategy is perfectly coherent with the model of CE, because it represents a solution to "manage change" (UNESCO, 2011) and "close the loops" (Gravagnuolo et al., 2017). In particular, the CE approach opens to new and innovative perspectives for the conservation strategies of cultural heritage and landscape. The adoption of the adaptive reuse approach to cultural heritage allows to determine multiple benefits (Architects' Council of Europe, 2018) acting as multiplier of values and creating local virtuous loops of value production.

This research work was carried out within the Horizon 2020 project "CLIC - Circular economy Leveraging Investments in Cultural heritage adaptive reuse"[2] that applies the circular economy principles to cultural heritage adaptive reuse for achieving environmentally, socially, culturally and economically sustainable urban/territorial development. The project is theoretically and practically interrelated to the international research, policy orientation and innovation activities on the role and impacts of cultural heritage/landscape for sustainable local development.

Starting from the awareness about the gap existing between the costs needed for the maintenance or reuse of cultural heritage and the scarcity of the available public resources, CLIC aims to define a transdisciplinary approach to identify evaluation tools to test, implement, validate and share innovative "circular" financing, business and governance models for systemic adaptive reuse of cultural heritage and landscape[3]. The regeneration of existing buildings through adaptive reuse can define a model for a more inclusive, resilient and sustainable development, playing a key role for the achievement of the CE goals and demonstrating the economic, social, environmental convenience of the adaptive reuse interventions as "multiplier of values" (Fusco Girard, 2019).

1.2 Heritage-based tourism and its impacts on accommodation facilities: some trends

There is a strong correlation between heritage and tourism, indeed heritage-based tourism is a specific market sector based on local heritage resources (Asmelash and Kumar, 2019). The sustainable tourism approach is that able to respect cultural integrity, environmental resources and that does not exceed the carrying capacity of tourist destinations (Lozano-Oyola et al., 2012). It follows that one of the most significant phenomena in recent years is undoubtedly represented by tourism, which needs to be managed wisely in order to avoid negative environmental, social, economic and cultural impacts (Fusco Girard and Nocca, 2017). Tourism is a sector in continuous development and, from an analysis of

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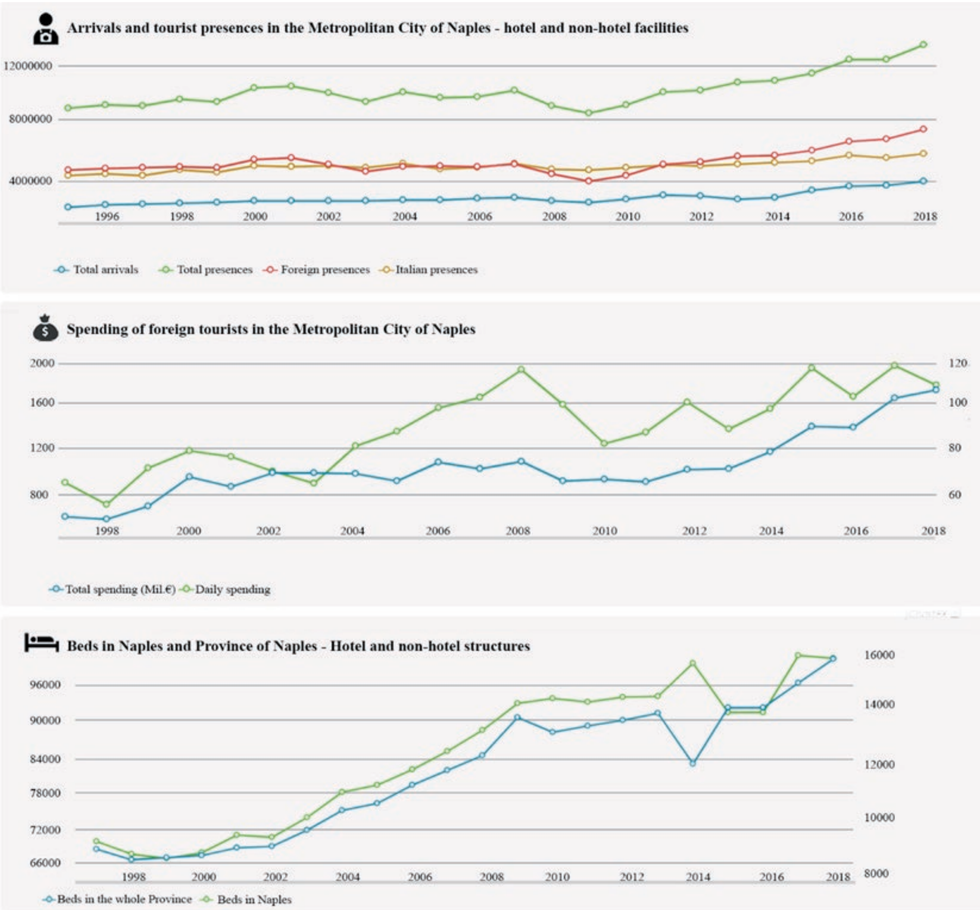
[2] CLIC has received funding from the European Union's Horizon 2020 research and innovation programme. The CLIC Consortium includes 15 partners and pursues to guarantee that the progress in the research and innovation on innovative circular business, financing and governance models for cultural heritage adaptive reuse is relevant and transferable in European cities and regions.

[3] More info about the project can be found at the following link: www.clicproject.eu.

Figure 1. Some tourism trends for Naples and its Metropolitan Area. Data of tourism trends come from the following sources: comune.napoli.it; dati.istat.it; eptnapoli.info; regione.campania.it. The graphic elaboration come from the following source: https://www.flapane.com/stats_turismo_napoli.php.



some current trends, it seems to be destined to increase also in the coming years (Figure 1).

Consequently, various types of accommodation facilities proliferate on the Italian territory, from the traditional Bed and Breakfast (B&B) to the more "airbnb" recent phenomenon. This determines the need to start some analyses that allow to propose development perspectives capable of integrating tourism into urban regeneration strategies, avoiding negative impacts such as those related to gentrification processes (Beauregard, 1985; Lieto and Beauregard, 2013) as well as the increase in traffic, pollution, noise, wastewater and resources consumption (Lozano-Oyola et al., 2012). The gentrification effect determines the removal of the residents from a certain area, following increases in the real estate values and changes in the intended use of the properties (Sassen, 1996), affecting the social and cultural fabric and causing an inevitable loss of identity of the cities (Becheri et al., 2018). Moreover, tangible and intangible cultural heritage could be affected if tourism development harms the maintenance of traditional values and severely damages the material cultural asset (Lozano-Oyola et al., 2012).

As already specified, one of the consequences linked to the intensity of tourism phenomena is the proliferation of non-hotel structures with a higher growth rate than those of hotels (Cipolla, 2018), causing repercussions on the market values of properties. These values can be influenced in various ways by numerous positive and negative externalities, not only related to the characteristics of the property, but also to the development dynamics of the surrounding areas and their attractiveness. In general, the analysis of real estate dynamics enable decision-makers to elaborate urban regeneration plans and projects (De Toro et al., 2020).

Starting from these reflections, this work is the result of an experimentation that investigates a portion of the historic centre of Naples where, according to some recent data, there has been a significant increase in B&B, often as the result of reuse processes linked to the built heritage. Consequently, the historic centre of Naples represents a fertile ground for investors who express their intention to start this business. Given the intensity of the phenomenon, the need to verify the existence of a relationship between the presence of accommodation facilities mainly linked to adaptive reuse phenomena and the dynamics of the real estate arises, relating as a result adaptive reuse and market values.

We therefore propose an experimental approach aimed at analysing these dynamics and putting them in relation with the territorial distribution of B&B, especially those that arose following processes of ancient historical residences adaptive reuse, of which the historic centre of Naples is rich. The methodology and its results are detailed in the following sections.

2. Methodology

2.1 Case study: some portions of the historic centre of Naples

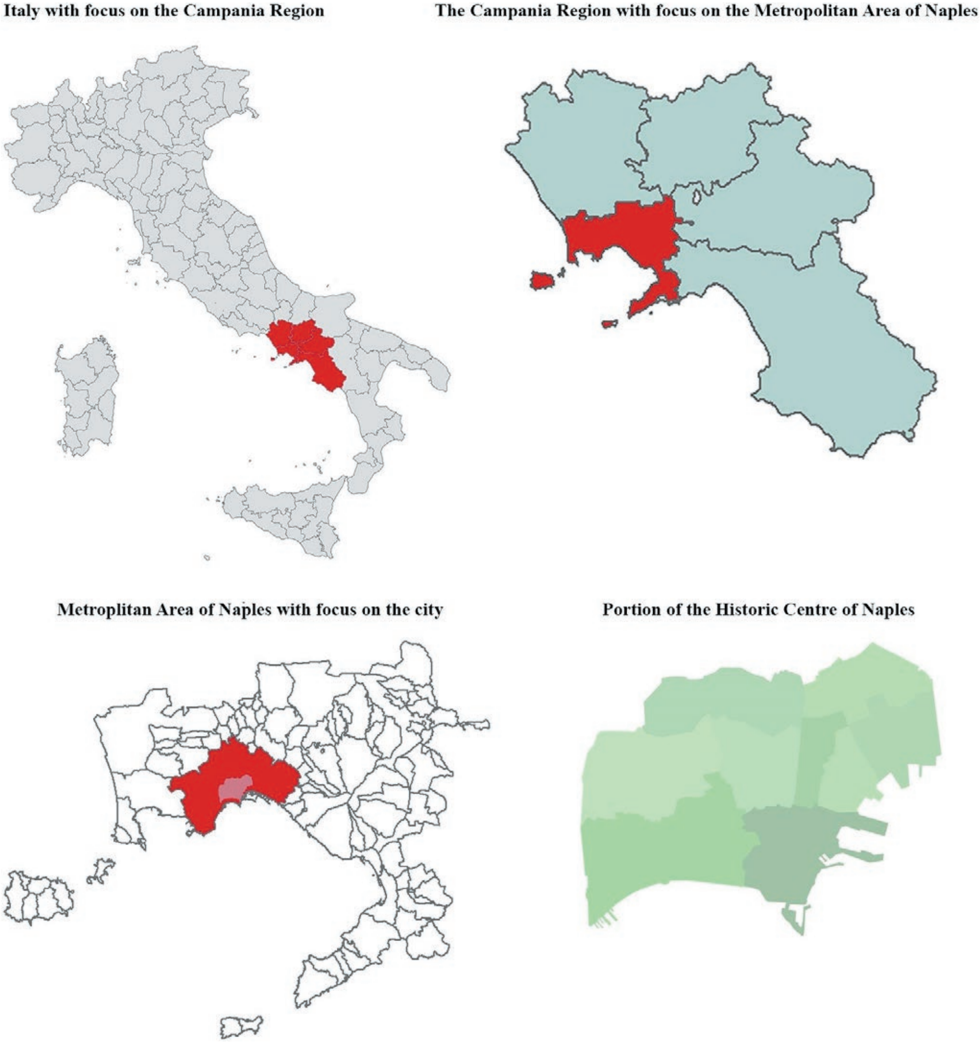
The case study selected for the experimental application is formed by a portion of the historical centre of the city of Naples (Italy), as characterized by the presence of neighborhoods with a strong concentration of B&B and which contains all the most important monuments of the city. The Municipality of Naples is divided into ten municipal offices[4] characterized by administrative decentralization and with organizational and functional autonomy.

In Figure 2 it is possible to understand the geographic entity and location of the selected area, that comprises the following neighbourhoods:

- Chiaia and San Ferdinando (District no. 1);

[4] According to the Italian Decree no. 267/2000

Figure 2. Geographical location of the selected case study.



- Avvocata, Montecalvario, Pendino, Porto, San Giuseppe (District no. 2);
- San Lorenzo (District no. 4);
- Vomero (District no. 5).

The city of Naples is part of the Metropolitan Area of Naples (MAN), which with its 92 municipalities and more than 3.5 million inhabitants, is the third most populated metropolitan area in Italy. An unregulated urban development, together with socio-economic and environmental disorder, characterize the MAN as a whole, determining a significantly chaotic territorial development, marked by the simultaneous presence of phenomena of density and dispersion of settlements (Formato and Russo, 2014). More in depth, the city of Naples today covers an area of 117.27 square kilometers with a population of approximately 1,020,120 inhabitants. Naples, with its universally recognized cultural and natural heritage, is famous all over the world and its historic centre is inscribed in the UNESCO World Heritage List. Furthermore, «Naples plays a leading role in the Italian urban landscape, and as it is the third largest city by population, it is at the centre of a vast metropolitan area and is a real laboratory of social and economic analysis. Naples belongs to the volcanic region near Vesuvius and Campi Flegrei, located in one of the most remarkable areas of the Italian seacoast and is characterized by a flat region that spans from east to west with a hilly stretch» (De Falco, 2018, p. 3). As a consequence, tourism in Naples is one of the main factor of economic development and Naples is the fifth destination among international arrivals in Italy after Florence, Venice, Milan and Rome that occupies the first place. Naples places itself at the eleventh place with around 3.7 million presences, equal to 0.9% of the overall national presences, and growing by 13.6% compared to last year[5].

The historical centre of Naples, with its architecture and monuments, still expresses the power that the city was able to achieve and confirm through the centuries. Also during the Middle Ages the Neapolitan settlement plays in Europe the role of a fundamental economic and cultural centre, confirming this supremacy also in the following 16th and 17th centuries, during which the city became one of the main European capitals.

In particular, under the Bourbon reign, huge building renovation projects were launched having as a result the high esthetic quality not only of the main monuments but also of the whole built heritage, visible especially in the streets of the historic centre (UNESCO, 1995).

The Neapolitan historical centre is configured as a territory very articulated in its physical, social and functional geography and consists of a regular network of streets to which is added the presence of sumptuous architectural vestiges interspersed with extensions and subsequent additions. This articulation contributes to the formation of spaces imbued with vitality and conditioned by local traditions, customs and lifestyles of the inhabitants (Gasparrini and Russo, 2010).

In the case of Naples, the reuse of historical buildings has contributed to increase the attractiveness of little known areas or parts of the city considered as dangerous by tourists, stimulating the creativity of the local community in creating a new tourist offer and new activities related to it. The rediscovered aesthetic value of many of these buildings has been a tool to raise the awareness of the community about the value of its cultural heritage, increasing care and renovation actions (sometimes conducted independently) on a broader context. This renewed sense of community, together with the cultural and symbolic value of goods, was the major factor of place branding process for the whole city[6] that led to the progressive in-

[5] https://www.ildenaro.it/turismo-istat-napoli-boom-di-presenze-in-un-anno-136/

[6] In recent years Naples has become one of the most followed Italian cities on social networks: it ranks third, after Turin and Bologna, for having achieved the best results in 2019 in terms of presence, activity, visibility, popularity and ability to involve users on social channels (www.forumpa.it/citta-territori/comunicazione-social-nei-comuni/).

Figure 3. Some examples of historical Neapolitan buildings hosting B&B.

Palazzo Ruffo di Bagnara
Place: Dante Square, Naples
Construction period: 16th century
Original property owner:
Royal Councillor Antonio De Angelis (1647), Francesco Ruffo, Bagnara Duke (1660)
Current property owner:
private property
Original use: residential (17th century), Purists' center (19th century)
Current use: b&b
Opening Date: 2013

Foro Carolino
Place: Dante Square, Naples
Construction period: 18th century
Original property owner:
Carlo di Borbone
Current property owner:
private property
Original use: food storage (17th century), commemorative monument (18th century)
Current use: b&b (right side), Convitto Nazionale di Vittorio Emanuele II (1861)
Opening Date: 2018

Palazzo della Grande Loggia
Place: Duomo Street, Naples
Construction period: 15th century
Original property owner:
private property
Current property owner:
private property
Original use: residential
Current use: residential, b&b, seat of Poland Consulate
Opening Date: 2018

Palazzo dello Spagnuolo
Place: Sanità Quarter, Naples
Construction period: 18th century
Original property owner:
Nicola Moscati marchese of Poppano (18th century), Spanish noblman
Tommaso Atienza (end of 18th century), Costa Family (19th century)
Current property owner: private and public property (Campania Region has only two apartments on the top floor)
Original use: residential
Current use: seat for cultural association, mueseum (2nd and 3rd floor), b&b (1st and 4th floor)
Opening Date: 2017 (b&b)

Palazzo Rinuccini
Place: Dante Square, Naples
Construction period:
end of 17th century
Original property owner:
Marchese Rinuccini (18th century), Donato Tommasi (19th century)
Current property owner:
private property
Original use: literary salon
Current use: b&b (1st floor), relais (3rd floor)
Opening Date: 2019

Palazzo Carafa di Maddaloni
Place: Maddaloni Street, Naples
Construction period: 16th century
Original property owner:
Cesare d'Avalos, Marquis of the Aragon Kingdom (16th century), Flamish Banker Gaspare Roomer (17th century), Carafa Family (17th century)
Current property owner:
private property
Original use: residential
Current use: residential, commercial (ground floor), b&b (1st floor)
Opening Date: 2011

crease in tourism in recent years (see Figure 1). This phenomenon has determined the tendency to reuse the historical Neapolitan buildings preferring the function of B&B, relais, luxury home, etc., having as consequence the inclusion of the city in new and virtuous economic networks, the generation of new jobs opportunities and growth and also the attraction of new kinds of users (Figure 3).

In this perspective, the adaptive reuse of historical buildings with particular cultural value has contributed to the process of democratization of culture because, through the public use, has allowed the fruition of places previously inaccessible (for reasons of ineligibility or for bureaucratic reasons) and the promotion of knowledge. This process has the capacity both to perpetuate the memory of the culture of the era in which the buildings were built and, at the same time, to create a circular educational and cognitive process. As a matter of fact, the fruition determined by the new use has as its main consequence that people do not "suf-

Table 1. Average houses prices in the city of Naples (authors' elaboration on BIN data 2009-2018).

Years	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Variation 2009-2018
Average houses prices (€/sqm)	2,930	3,050	3,060	2,830	2,740	2,610	2,540	2,450	2,380	2,370	-19.1%

fer" the history of the building, but they manage to live it in a new way, attributing it new value. Consequently, the new functions are brought together with the heritage values in an active and meaningful dialogue, through which people strengthen the perceptions of their own traditions and history, providing new future perspectives for the areas that become better adapted to the needs of multi-ethnic and multi-cultural societies (Architects' Council of Europe, 2018). As previously already specified, the ever-increasing tourist demand in Naples determines the growing increase of accommodation facilities on the territory. Given also the significant presence of historic buildings, many of this accommodation facilities in the form of B&B arose in the ancient noble palaces of which the city is rich, especially in the last 6-7 years[7].

The aim of the paper is that of verifying the possible correlation between adaptive reuse of cultural heritage as a means to develop hotel and especially non-hotel structures and the trends of the real estate in Naples. As a matter of fact, De Toro et al. (2020, p. 5) point out that «Naples is the city in southern Italy that is growing most in terms of real estate sales. The Neapolitan market was the only one, in fact, to recover following the decline in real estate transactions begun with the economic crisis, which in the South of Italy led to halving sales. At the end of 2018, the real estate market of Naples returned almost to the values of the pre-crisis period, with a growth of 10.5% of transactions compared to the previous year».

At the same time, it must be considered that the average values of housing have decreased in almost all the neighbourhoods of the city in the period 2009-2018. In Table 1, the average houses prices for the city of Naples and the percentage variation between 2009 and 2019 are reported for each year.

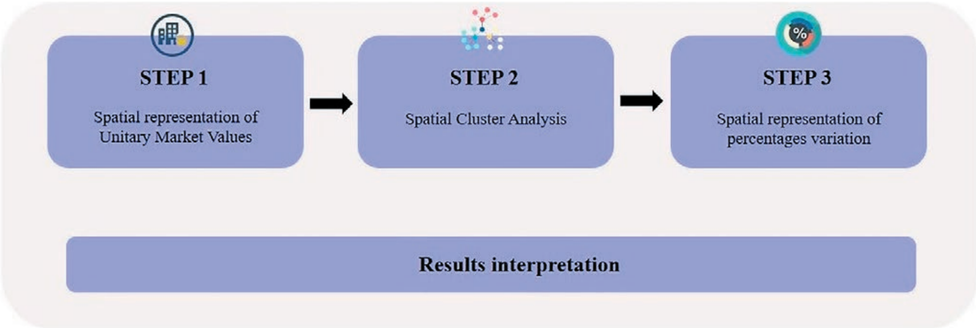
2.2 The three steps for the spatial identification of real estate market values

The experimental application can be divided in three main methodological steps (Figure 4).

The first step is the spatial representation of the Unitary Market Values (in Italian Valori di Mercato Unitari – VMU) of residential buildings through the use

[7] This aspect has been confirmed through a little survey to the owners of some of the considered facilities.

Figure 4. The methodological steps.



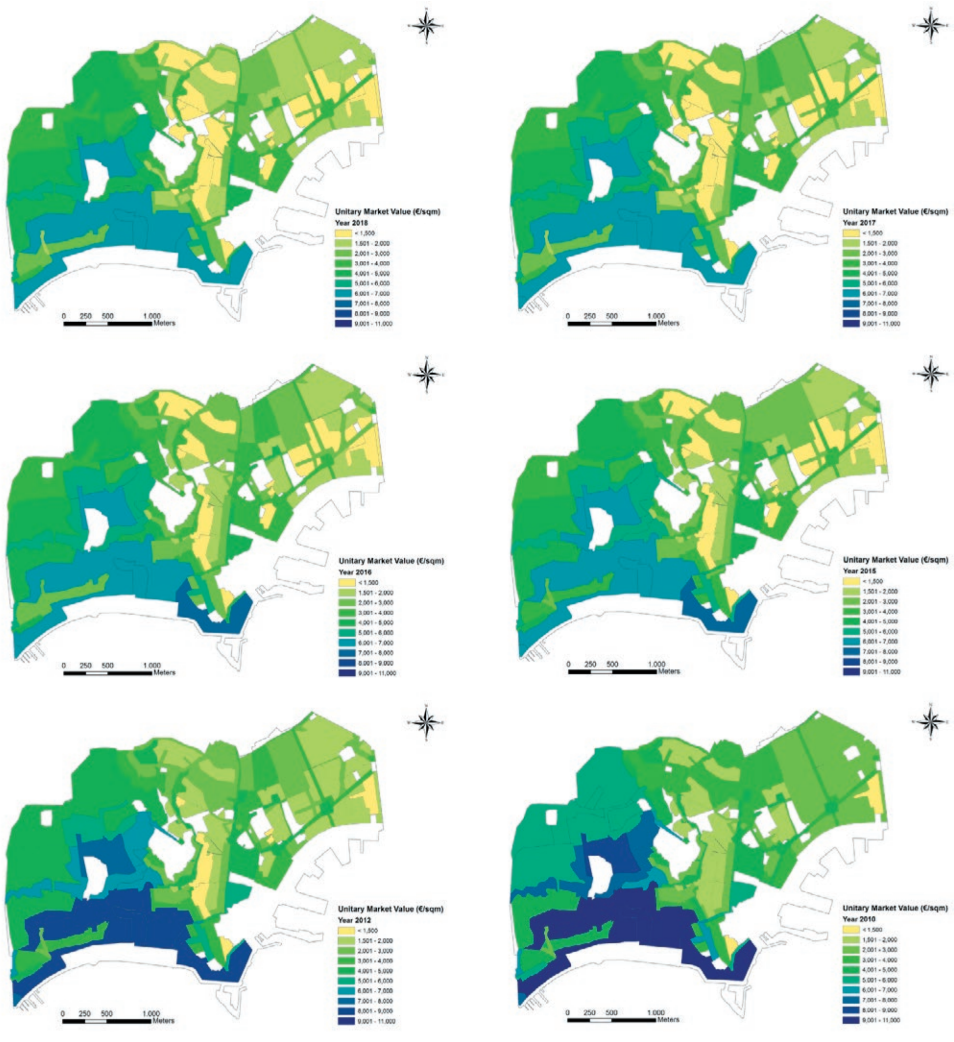
of Geographic Information System (GIS), in order to observe the temporal evolution of this values according to their territorial distribution and to some significant reference years (2010, 2012, 2015, 2016, 2017, 2018) (Figure 5). Data about market values of residential buildings for the selected case study have been provided by the real estate stock exchange of Naples (In Italian: Borsa Immobiliare di Napoli - BIN) that each year collects these values divided according to the Neapolitan neighbourhoods.

In particular, we have analysed the last four years available (2015-2018), i.e. the last data published by BIN, which also correspond to the years in which the phenomenon of the reuse of the built heritage as B&B has mainly manifested. Furthermore, two years (2010 and 2012) were considered in which the effects due to the 2008 crisis were recorded in the Naples real estate in order to have a significant reference. The analysis of even intermediate years (2011, 2013 and 2014) does not allow to appreciate significant differences with the previous and following years, obtaining very similar maps of market values. When the elements of the issue under analysis are characterized by a clear and evident spatial component, it is possible to use thematic maps as representative means (De Toro and Iodice, 2016; De Toro and Iodice, 2018).

In the present application, the use of GIS allows to acquire, store, extract, transform, and visualize spatial data from the real world (Burrough, 1986) and helps to spatially visualize how market values are distributed over the territory.

The second step of the application is represented by a Cluster and Outlier Analysis in order to observe the spatial distribution of homogeneous real estate values according to the same years of reference (Figure 6) and identify similarities of behaviour between data spatially close to each other. This happens through the use of the Anselin Local Moran Statistics Index to determine the relationships among data (Moran, 1950; Anselin, 1995). In general, a spatial cluster has been defined as «an excess of events [...] or values [...] in geographic space» (Jacquez, 2008, p. 395) and the higher the value represented by the cluster, the stronger is the presence of similar values (high or low) in spatially close areas. When the value is negative, it means that there is a discrepancy between values that, although they

Figure 5. Unitary Market Values of the real estate values for some Neapolitan neighbourhoods, authors' elaboration through GIS.

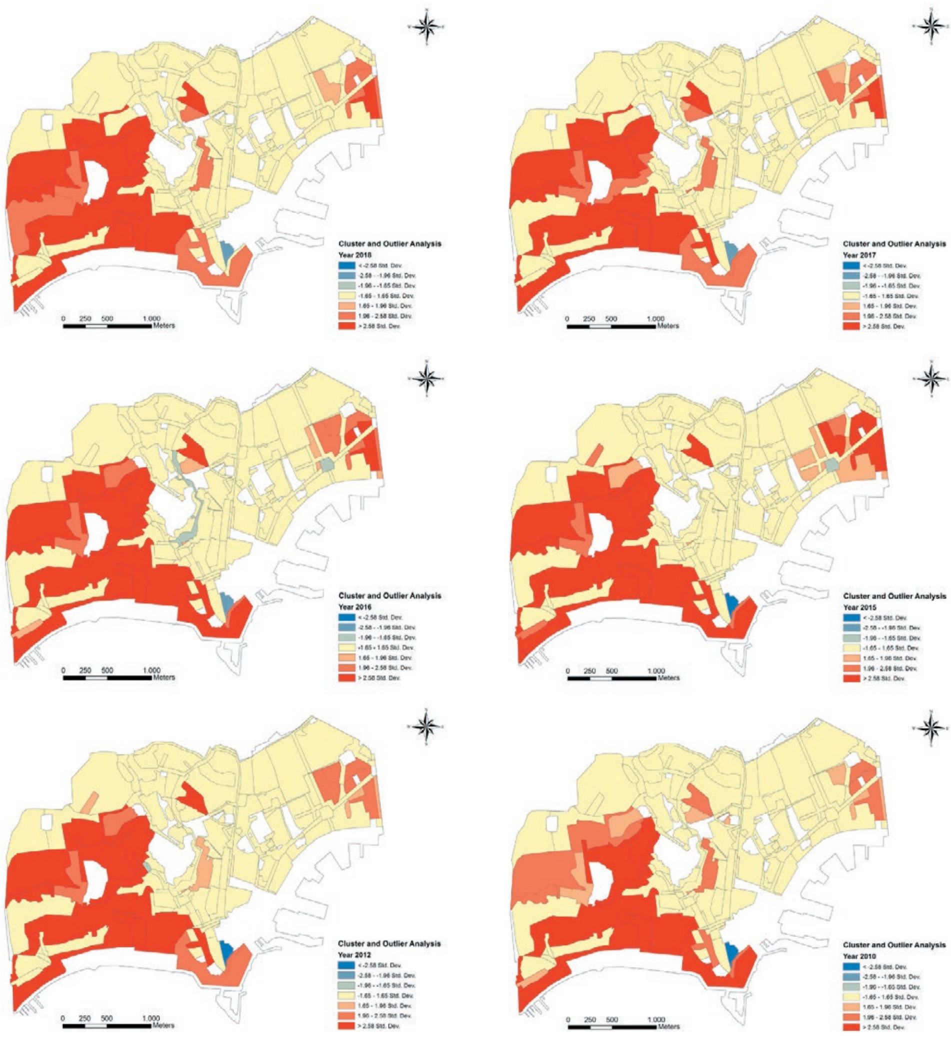


belong to nearby areas, have different values[8].

The third and last step of the methodology is represented by the spatial representation of the percentage variations of the Unitary Market Values, comparing year 2018 with each of the previous analysed years (Figure 7). The more negative

8 For a more detailed technical description of the Cluster and Outlier Analysis see De Toro et al. (2020) in which the same analysis has been carried out for the whole territory of the Municipality of Naples.

Figure 6. Cluster and Outlier Analysis of the real estate values for some Neapolitan neighbourhoods, authors' elaboration through GIS.

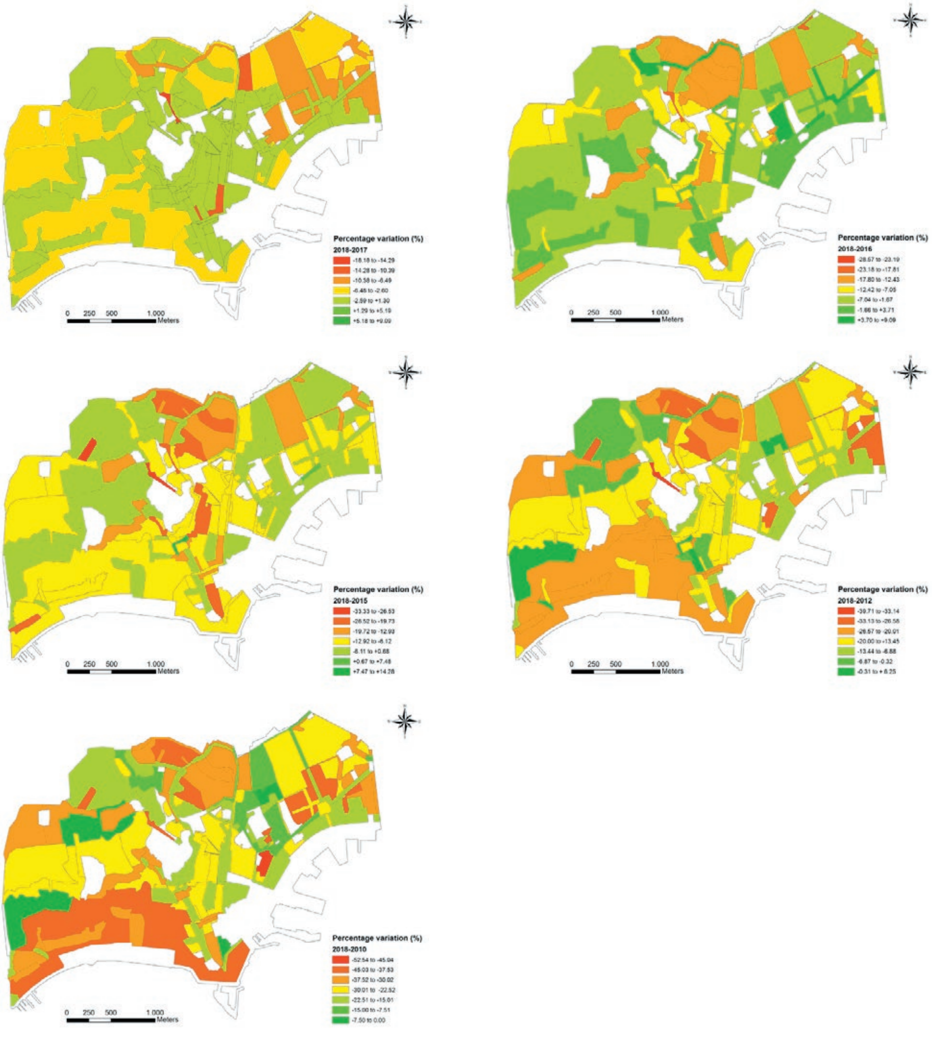


are the values represented for an area, the higher is the decrease of market values that occurred between the two years compared.

3. Results and Discussion: is there a correlation between market values and accommodation facilities?

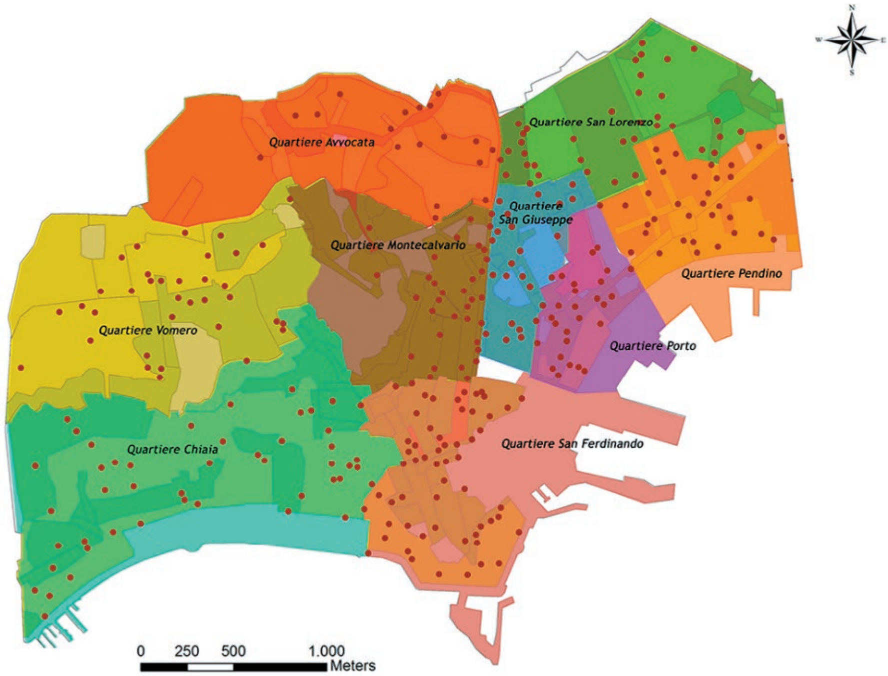
The first analysis (see Figure 5) shows the spatial distribution of the Unitary Market Values of residential buildings in the years 2010, 2012, 2015, 2016, 2017 and

Figure 7. Percentage variations of the real estate values for some Neapolitan neighbourhoods, authors' elaboration through GIS.



2018. The values have been organized into ten classes: < 1,500 €/sqm, 1,501–2,000 €/sqm, 2,001–3,000 €/sqm, 3,001–4,000 €/sqm, 4,001–5,000 €/sqm, 5,001–6,000 €/sqm, 6,001–7,000 €/sqm, 7,001–8,000 €/sqm, 8,001–9,000 €/sqm, 9,001–11,000 €/sqm. The areas in white correspond to the green areas that in this analysis do not present residential buildings and so do not present any spatial distribution of market values. Observing the maps, it is possible to notice that market values in all areas have undergone a decrease over the years, but their spatial distribution has maintained a certain homogeneity, showing the highest values concentrated especially

Figure 8. The neighbourhoods of the city of Naples overlapped by the B&B.



in the neighbourhoods of Chiaia, part of San Ferdinando (the side close to the Chiaia neighbourhood) and part of Vomero (the area of Vanvitelli square) (Figure 8)[9].

In these neighbourhoods the market values have changed from the highest class of values in 2010 (9001–11000 €/sqm), to the medium-high class in 2018 (6,001–7,000 €/sqm). Furthermore, in the same parts of the city, the values have changed a lot in a period of eight years (3,000–4,000 €/sqm fewer), while in other parts of Vomero neighbourhood, also included in a high class of value, there was not a significant variation. More in depth, in 2010 the areas of Sant'Elmo Castle and the Aniello Falcone and Tasso streets were included in the medium-high class of value (6,001–7,000 €/sqm), while in 2018 they had a value of 5,001–6,000 €/sqm.

The same trend is visible in the areas that in 2010 were included in the medium and low class of market values (San Ferdinando, Avvocata, Montecalvario, Pendino, Porto, San Giuseppe and San Lorenzo neighborhoods) that until 2018

[9] The figure shows the Neapolitan neighbourhoods overlapped by the red points that represents the B&B located in the historical centre. This figure and can be considered as a reference for the results description.

have changed their class of values moving about 1-2 positions less (corresponding to a negative variation of 1,000–2,000 €/sqm). At the end of this first step of analysis, it can be concluded that the areas that have suffered the greatest decline in real estate values are those belonging to the highest value ranges.

The second analysis, i.e. the Cluster and Outlier Analysis (see Figure 6 above), demonstrates the spatial distribution of the decrease trend, taking into account if it is homogeneously concentrated in some areas, creating "cluster" of values. It also shows that the more clustered neighbourhoods are those that in the previous analysis were characterized by high market values (neighbourhoods of Chiaia, part of San Ferdinando with the side close to the Chiaia neighbourhood and part of Vomero, in particular the area of Vanvitelli square). Added to these, other strongly clustered areas are also those characterized by medium-low values: the Pendino neighbourhood close to Garibaldi station, the areas around Montesanto metropolitan station in Montecalvario neighbourhood and the side of the Spanish Quarter close to the area surrounding Sant'Elmo Castle and included between the Montecalvario and San Ferdinando neighbourhoods. In this analysis an exception is represented by the area delimited by Plebiscito Square, Monte di Dio street, the Vittoria tunnel and Underground Naples in San Ferdinando neighbourhood. As a matter of fact, this area in all the analysed years, presents always the same class of residential market values (< 1,500 €/sqm) which is very different with reference to the values of the close areas.

The third and last analysis (see Figure 7) shows how the value of the residential real estate market has varied in terms of percentage comparing the year 2018 with each of the previous analysed years. The results of this analysis are linked with the observation of the first analysis for the neighbourhoods of Chiaia and part of San Ferdinando (the side close to the Chiaia neighbourhood) in which, comparing the year 2018 with 2010, it was registered the more significant variation (represented through hot colour). In addition to these, also other areas have had an important variation: the areas of Pendino neighbourhood close to the Garibaldi station, those including the Montesanto metropolitan station, Dante square and Pontecorvo street in Montecalvario neighbourhood, the area around Collana Stadium in Vomero neighbourhood and the part of the Avvocata neighbourhood that includes Salvator Rosa street.

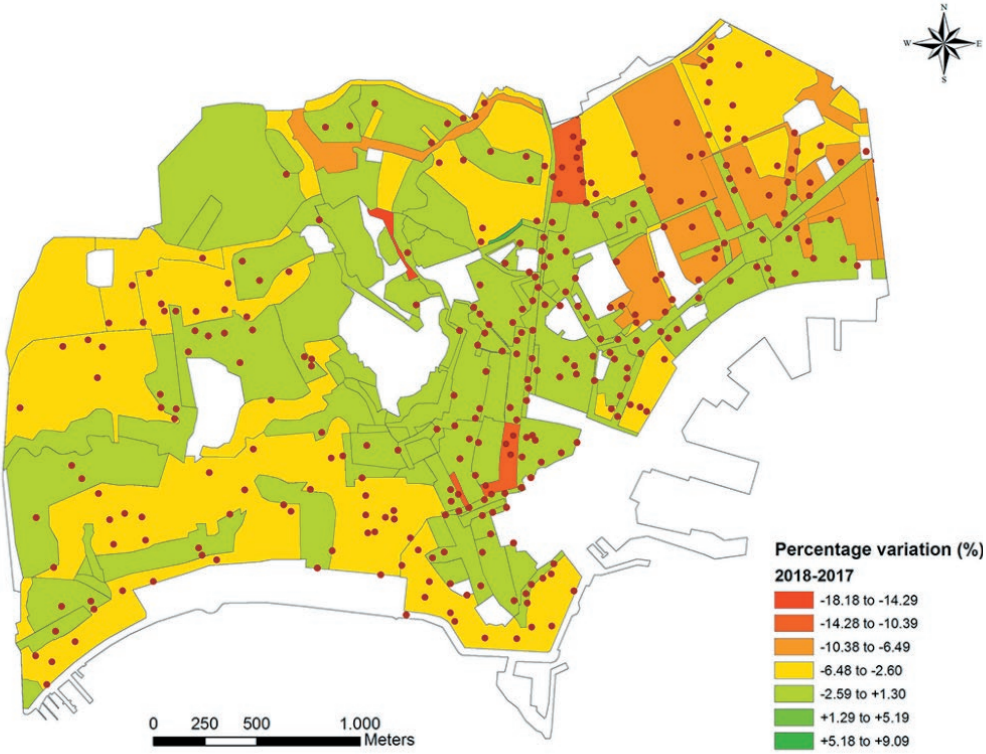
The other part of the map show a less significant variation, with the lowest percentage values in the area of the Vomero neighbourhood, included between Tasso street and the limit of Chiaia Neighbourhood, and the historical centre.

The percentage values of the variation decrease as they are compared years closer and closer to each other.

At the end of these three analysis phases, a final analysis was made to demonstrate the existence of a correlation between the variation of the real estate residential market values and the presence of B&B (Figure 9).

Observing the map, at a first glance it is already possible to notice that the area with the major concentration of B&B is the historical centre, including the neighbourhoods of san Ferdinando, Montecalvario, San Giuseppe, Porto, Pendino and San Lorenzo.

Figure 9. B&B map, authors' elaboration through GIS.



This localization confirms the trends described in the paragraph 2.1 of reusing the historical Neapolitan buildings as touristic accommodation, since in this area the reuse is the only solution to settle new activities, while respecting and valorising the existing built heritage.

Overlapping the map with the B&B localization to the map that represent the percentage variation between 2018 and 2017, it is evident that, where there is a concentration of B&B, often the market values are quite stable or increasing, comparing them to the previous years. Surely the presence of B&B is not the only determining factor for the evaluation of the variables that influence the development of real estate values, but it can reasonably be assumed that the improvement of the aesthetic quality of reused buildings and the reactivation of economic dynamics in the whole context foster a positive evaluation of the properties located in the regenerated area and represent a "positive externality" for the real estate market evaluation.

4. Conclusions

In conclusion, it is possible to confirm that in a CE perspective, adaptive reuse has the capacity of:

- activating a symbiotic relationship between cultural heritage and its context;
- stimulating a generative capacity for the activation of new activities in the context;
- stimulating a regenerative capacity able to reactivate the economy of existing activities and also the social bonds among the actors involved in the reuse process;
- minimizing environmental impacts (adopting energy efficiency systems, water recovery systems, avoiding soil consumption derived from the construction of new buildings and maximising the potential of the existing ones) (Fusco Girard and Nocca, 2019).

On the one hand, the reuse in general is considered as an action that gives an added value to the regenerated resources, re-starting a new life and using the whole potential embedded in them; on the other hand, cultural heritage is recognized by the European Union as a key economic resource in the global competition (European Commission, 2015).

In this perspective, the reuse proposal is not only a problem of conservation of physical and natural systems but also of social and cultural ones, which represent the particular identity of a city and of its organizational structure. The adaptive reuse of abandoned and underused cultural heritage and landscapes represents a strategy to implement in the cities the paradigm of sustainable development, starting from the existing goods and re-adapting them in the actual and modified contexts. Cultural heritage can be considered as a resource and a resilient factor of urban settings, able to incorporate the change (technological innovation and contemporary cultural production) and to transform it through a creative process. Adaptive reuse aims to prioritize, exemplify, and integrate circular, inclusive and sustainable values in the processes of heritage conservation. It offers also a better chance to overcome the threats of mass-tourism or modern urban development (Gravagnuolo et al., 2017).

The reuse intervention increase the attractive capacity of the asset, extending this positive effect also to a wider context. This productive capacity is demonstrated by the "external effects" generated at economic, social and environmental level and also in terms of new use values recognized to the cultural asset, both from the private and the social perspective, that tends to last in the longer-term (Gravagnuolo et al., 2017), reflecting as well the characteristics of the CE model (de Jesus et al., 2017; Kirchherr et al., 2017).

The adaptive reuse technique can be a key driver of economic growth, social wellbeing and environmental preservation, contributing to sustainable development of cities and regions (European Commission, 2014, 2015; CHCfE Consortium, 2015; European Parliament, 2017).

Through a critical analysis of the described work, it is first necessary to recognize that the real estate market is affected by several factors and therefore a more comprehensive investigation would be required. A significant example is the analysis performed by De Toro et al. (2020), where it has been highlighted that in the city of Naples houses market values are also influenced by other variables such as: the introduction of new pedestrian areas, the construction of new subway stations, the redevelopment of open spaces, the settlement of new university locations, the creation of spaces for trade, crafts and leisure, etc. However, in the considered areas of the historical centre of the city, some of these interventions have already been carried out some years ago and surely the reuse of the built heritage for tourist hospitality represents a recent and significant phenomenon.

Indeed, it is clearly evident that where there is a concentration of non-hotel accommodation activities in the form of B&B, market values often show a holding or a recovery compared to the previous years. It is also shown that some urban areas display a greater homogeneity in real estate dynamics and therefore a more extensive analysis that includes further significant urban areas could be interesting. In addition, where there is a concentration of non-hotel tourist activities, the latter are often the result of cultural heritage adaptive reuse in the historic centre of Naples and it is therefore possible to hypothesize a correlation between the reuse of heritage and the real estate market, however underlining the need to take into consideration other factors that may allow for a more comprehensive investigation.

Author Contributions

Conceptualization: Martina Bosone and Silvia Iodice; methodology and data curation: Pasquale De Toro; formal analyses: Pasquale De Toro; writing, review and editing, Martina Bosone and Silvia Iodice. All authors have read and agree to the published version of the manuscript.

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The role of fiscal and monetary policy in stimulating Circular Economy in Iraq

The issue of the Circular Economy is not a new issue to several countries, especially the developed ones. Here in Iraq it is considered newly introduced, despite the few attempts to establish projects that concern recycling most of them were doomed to fail, due to two main reasons: the first one is the financial and administrative corruption widespread in all departments of the country, the second one is the priorities of public spending. It is well known that Iraq was subjected to two major attacks, the ISIS entry attack in 2014 to Iraq. ISIS occupied about a third of Iraqi lands which resulted in a collapse in oil prices, as Iraq depends almost entirely on oil revenues in its budget which is the second attack. This made the Iraqi governments point public spending towards the priority of preserving national security and liberating Iraqi lands. Therefore, the circular economy project proposals were not considered a priority under these circumstances.

1. Introduction

In the past decade, the circular economy (CE) has established itself as an influential model for economic development, with the Chinese government and European Union being the first to follow this policy in their country. The goal of the model is to create circularly material that flows to break the current linear economic state, taking into consideration creating business value for its participants. (Corvellec et al., 2020, p. 98).

The CE concept invites societies to reevaluate their use of waste and resources. The concept proposes the replacement of the current "take-make-use-dispose" system, with a system that addresses structural waste - encompassing visible, and hidden forms of waste. For example, recycling materials as opposed to landfilling or incinerating, and the intensive use of them through cascading approaches, as well as sharing and ownership models. The application of circular strategies in addressing structural waste to improve resource efficiency, productivity and reverse resource loss. (Blomsma and Tennant, 2020, p. 1).

The implementation of circularity materials is increasing in developed countries, while the developing countries are still struggling to transition to the circular economy due to the lack of economic funds, public awareness and political will, among other reasons. Developing countries like China, Serbia and India started to implement such principles meanwhile, low-income countries are commonly introducing new projects or plans with no effectiveness. (Ferronato et al., 2019, p. 367).

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The study aims to find the answer to these questions. Firstly, does Iraq have the basic elements for the transition to a circular economy? Secondly, what is the best source of funding to stimulate the transition to the circular economy in Iraq? The government by its fiscal instruments or monetary policy by banks will be more suitable? Lastly, what will be the results of the Iraqi economy if circular economy projects were implemented?

2. Literature Review

2.1 The concept of circular economy

The CE goes beyond recycling and is based around a restorative industrial system focused to treat waste as a resource. Whenever a product reaches the end of its useful life, the attempt is made to keep the materials within the production boundary and use them productively enough to create further value. In developing economies, the waste is being treated in the reduce, reuse and recycle (3R) concept under a broader concept of the circular economy. The CE is an industrial economy that is: restorative by intention; aims to rely on renewable energy; minimizes, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design. In the circular economy model, durable goods would be designed so that they could be repaired rather than replaced, as well as biological materials to be managed so they could be returned to the biosphere without contamination. Coincidentally, the implementation of a circular economy is specifically based on both resource efficiency, eco-efficiency, and its purpose is to acquire a set of key measures to move to a more circular, green, and sustainable economy (Ghosh, 2020, pp. 3-4).

The concept of CE can be described through some of its components or strategies (like reusing, recycling, eco-design and performance economy). However, this is not sufficient if the aim is for a socio-economic system which has a resource-based point of view. The components have to be seen as parts of a larger system, or an ecosystem (Desing et al., 2020, pp. 2-3). In other words, in 2012 the Ellen MacArthur Foundation (EMF) introduced the concept of CE as "an industrial economy that is restorative or regenerative by intention and design", and later as "restorative and regenerative by design and aims". Since then, the definition of CE as restorative and regenerative has come to a common use or at least have reflected thousands of times throughout both academic and non-academic literature. This definition is by far the most employed one in CE studies. (Morseletto, 2020, p. 1).

There are five priorities characterized by specifications of their product or value chain, and their environmental footprint or dependency of material from outside. These priorities are represented by (Di Maria, 2020, p. 206):

- Plastics: Plastic materials are widely used in different products from packaging to vehicles. Currently. In the European Union (EU) about 25% is recycled and about 50% is landfilled. Improper plastic management causes also ocean pollution with a very high environmental burden.

- Food waste: Food production, distribution, storage and use generated in high impact increased edible food disposal. Furthermore, food waste happens at all levels of the value chain from production, reaching the final user (e.g. restaurants, canteen, home) making its quantification very difficult. The European Commission will elaborate a uniform calculation methodology for addressing these amounts. Data marking is also an issue to be addressed that usually did not indicate the expiration date. A wrong interpretation of this also causes a large generation of food waste.
- Critical raw materials: These are represented by high value and vulnerable supply distribution materials, known as electronic waste. The recycling rate will be hence improved, and the Commission will promote this activity.
- Construction and demolition waste: They are considered one of the largest amounts of waste generated in the EU. A lot of recyclables in such waste continue to be disposed of. Quality standard and selective demolition procedures are one of the main criticisms for their recycling. Green public procurement is also another important aspect to implement increasing construction and demolition waste.
- Biomass and bio-based products: Biomass can play an important role in replacing fossil and mineral resources for the production of fuels, energy and chemicals. In any case, it is mandatory to be analyzed with attention to the sustainability of the supply chain to the environmental impact. Wood packaging recycling will be also increased. Research funding for supporting the EU bio-based economy is also a fundamental factor for the full implementation of CE.

2.2 *Finance Sources of the Circular Economy*

Transitioning to the circular economy will require a large number of economic resources to be invested in target sectors. Like any other type of expenditure, investment needs to have firms at their disposal for a sufficient amount of financial means. Given the upfront costs of investments, firms are typically unable to finance them through their savings and thus necessitate access to external finance. In other words, they need to borrow or receive money from the government before being able to invest (Campiglio, 2016, p. 220).

King and Levine (1993) reiterate Schumpeter's idea of the key role played by financial institutions in appraising, managing and financing businesses. They also mention that investment decisions are made based on cost and benefit analysis. Subsequently, financial institutions mobilize funds from individual investors (surplus units) and finance the activity of the entrepreneur (deficit units), it is cost-effective for institutions more than individual investors (Acheampong, 2016, p. 29). Therefore, a new role for monetary and fiscal policy by finance the projects of the circular economy (innovation economy) is required by implementing unconventional policies. On the other hand, an explanation of the role of both monetary and fiscal policy will provide some financial resources to establish the valid circular economy.

2.2.1 Fiscal policy

The circular economy has received increased attention from policymakers in industrialized countries and is currently promoted by the EU as well as several national governments including China, Japan, UK, France, Canada, The Netherlands, Sweden and Finland. Research studies on how to stipulate appropriate policies that promote the circular economy suggests that governments should play a leading role by reforming existing laws, enacting new regulations, promoting the application of new environmental technologies, and organizing public education. Government policies can affect the cost of production and the supply curve through taxes, regulations, and subsidies. Other examples of policy that can affect cost are the wide array of government regulations that require firms to spend money to provide a cleaner environment or a safer workplace (Rabta, 2020, pp. 3-4).

Therefore, if governments wish to encourage investors to finance circular economy projects in the future, clear and consistent policies over a long period are needed. On one hand, the government needs a clear signal in terms of tax reduction on some activities that have a relation with the circular economy (e.g. plastic recycling projects). Government incentives and guarantees can also be used, from support for Research and Development (R&D) which affects operational efficiency to invest incentives (capital grants, loan guarantees and low-interest rate loans), taxes (accelerated depreciation, tax credits, tax exemptions and rebates), and price-based policies at the output stage (which affect revenue streams - e.g. feed-in tariffs), or policies which target the cost of investment in the capital by hedging or mitigating risk (Della Croce et al., 2011, p. 10). In addition to that, one of the vital instrument that could stimulate the move towards circularity is an adapted tax system. Currently, introducing circular products is harder, because they compete with products derived from "tax-free" pollution: virgin raw materials are too cheap to acquire and dispose of.

At the same time, high labor costs hold back labor-intensive R&D efforts as well as service-oriented business models, which inhibit the transition. The current tax barrier could be turned into a catalyst for the circular economy by applying the "polluter pays" principles and shifting taxes from labor to consumption and natural resources. The goal is to enable growth based on human capital rather than the extraction of natural resources (Goovaerts and Verbeek, 2018, p. 208). On the other hand, the government must impose taxes that achieve an environmental goal. Environmental taxes are environmentally effective, i.e. they contribute to the achievement of the environmental objectives for which they have been designed. The tax must be set at the right level to achieve the objectives and must be directed at the source of the environmental burden to be reduced. When it is implemented in this way, it is clear that numerous examples of environmentally-successful green taxes, among which may be mentioned the Danish energy/carbon taxes, the Swedish NOx tax, the German energy and transport taxes, the UK climate change levy and fuel duty escalator, the Finnish, Swedish and UK waste taxes, the London congestion charge and the Dutch wastewater effluent charge (Ekins et al., 2009, p. 24).

Thus, fiscal policy will be more efficient by using its financial tools to encourage the projects of circular economy and reduction of pollution, then more chances will be obtained from achieving sustainable development. Overall, fiscal tools provide a stimulus to producers and consumers to change their behavior towards a more eco-efficient use of natural resources by stimulating technological innovation and reducing consumption levels. Governments at all levels can also use a variety of non-fiscal tools to promote the development, uptake of circular economy-related technologies and services by modifying the attitudes, behavior of producers and consumers towards natural resources (Brears, 2018, p. 31).

Finally, the state can use both fiscal and monetary policies by coordination in some procedures to encourage the projects of the circular economy. For example, the Chinese experience which adopted Taxation, fiscal, pricing and industrial policies were introduced. A fund was allocated to support the conversion of industrial parks into eco-industrial agglomerations. Tax breaks were provided to enterprises in the reuse sector. To finance the initiatives through concessionary loans or direct capital financing, the National Development and Reform Commission (NDRC) joined with financial regulators including China's central bank and securities regulatory commissions (Mathews and Tan, 2016, p. 441). This coordination will be reflected on efficient domestic financial intermediation is likely to support the transition to the circular economy more effectively if there is some co-investment by the public sector (government), this will provide credibility about long-term strategy and if public agencies take the responsibility of the political risk associated with policy uncertainty. Specialized banking intermediaries (Development Banks and Government Banks) may have a role to play in this regard (Bowen et al., 2014, p. 32).

2.2.2 Monetary Policy

First coined by Keynes (1913) in the context of central banking in developing countries, promotional objectives have usually only been stated in the statutes of central banks in developing and emerging economies. Regardless of those of advanced economies' central banks, where at most promotional objectives were informally conveyed. Nevertheless, the central banks have numerous powerful tools at their disposal to affect credit allocation and the investment behavior of financial firms. Whether and to what extent a central bank should use its powers and actively engage in the circular economy by encouraging the financial system to promote projects involving circular economy. They depend on two main factors: its legal mandate, and the extent to which it is best placed to correct certain types of market failures. Considering the ability and suitability of other policy institutions to steer the circular transformation (Dikau and Volz, 2020, p. 12).

So, the monetary policy may have a big impact on the transition process to the circular economy. There are three families of existing propositions of funding mechanisms based on unconventional monetary policies targeting green or climate investments. These "Smart Unconventional Monetary" (SUMO) policies are:

(*i*) the use of Special Drawing Rights (SDRs) issued by the International Monetary Fund (IMF); (*ii*) Green Quantitative Easing (Green QE); and (*iii*) the issuance of Carbon Certificates. Special Drawing Rights are international reserve assets, the original role of it was to supplement the foreign exchange reserves of the IMF's member countries. They are issued by the IMF and granted to the member countries according to their quota-share, which depends on their wealth. The idea here is to use existing or newly issued SDRs to capitalize an international climate fund that would provide grants and low-interest rate loans to fund low-carbon projects in developing countries (Ferron and Morel, 2014, p. 9).

Proponents of these SUMO mechanisms have identified a strong potential in terms of providing substantial low-cost funds to green projects and reducing the risks linked to green investments for private investors. Green QE and Carbon Certificates mechanisms are estimated by different proponents to generate hundreds of billions of dollars per year while staying in the proportions of QE policies that have been conducted in the United Kingdom and the United States. The justification for quantitative easing was the lowering of interest rates. It was hoped this would encourage spending whilst providing the banks with cash from the proceeds of the sale of their gilts lend to business (Murphy and Hines, 2010, p. 7). Regarding SDRs, the proposed scale of funding of most proposals is based on $100 billion per year as the amount in developed countries have devoted to low carbon development in developing countries.

Green QE is an unconventional monetary policy where the central bank enlarges its balance sheet to buy great quantities of assets, thus releasing great quantities of cash. The idea here is that those liquid assets could be used to finance low-carbon projects, thus triggering a green recovery that would lead to job creations and transition to a low-carbon economy.

Finally, the Carbon Certificates mechanisms consist of the central bank issuing new liquid assets providing low-carbon projects with low-cost debt through commercial banks. This debt can then be repaid using certificates (Ferron and Morel, 2014, p. 3).

3. Methodological approach

Relying on the deductive methodology, a type of deductive reasoning is used by modus tollens, or "the law of contrapositive" reaching to facts and reality that relates to the circular economy in Iraq by look for the actual projects of circular economy and all areas that concern it in Iraq (Blaug and Mark, 1992, pp. 4-5). Also, numbers and data from official institutions were analyzed: Ministry of Environment, Central Bank of Iraq, Ministry of Industry, etc. By using descriptive analysis of that data to discover the problems that Iraq suffers within the scope of the circular economy. The problems were cited by surveying CE projects which are really in work and another CE project which is still studied in Iraq.

4. The Circular Economy in Iraq: reality and ambition

4.1 The sight of the Iraqi economy

Transforming Iraq into a market economy is particularly challenging because the features that made Iraq function as a command economy are precisely the opposite of those needed for a market economy. Iraq lacked any of the legal, regulatory, political, and economic institutions which form the basis of market economies. Saddam's command economy had its relatively successful moments: before 1990, Iraq was one of the most prosperous and economically advanced countries in the Arab world, boasting a sizeable middle class; technical capacity; and has a relatively high standard of education and health care compared to other Middle Eastern countries, as well as high numbers of women educated and contributing to the economy (Crocker, 2004, p. 74).

After 2004 started the "Rehabilitation" process the economy of Iraq. Rehabilitation is defined here as a reversal of the process of decline. Through the utilization of existing production capacities, the reintroduction of capital accumulation, the reinvigoration of economic agents, the restoration of a measure of efficiency to markets, the preservation and development of skills, the rebuilding of key elements of the physical infrastructure, maintenance of existing facilities, and the achievement of balance, stability. This previous definition comes from that the economy during the 1990s has been going through a process of fragmentation and disintegration - a gradual and slow process that continues to decline accumulated capital assets and deplete natural resources. Through this prolonged process, the economy and society are shedding resources, institutions and skills which are needed for any rapid recovery (Mahdi, 1998, pp. 41-42). The greatest effect of the 2003 war on Iraq's economy was the subsequent decline in oil and electricity production. Oil production had been running at 2.5 million barrels per day before the war. It dropped to near zero in April 2003 exports ceased until June 2003. Electricity generation fell by about 25 percent, regaining pre-war levels in October 2003. Based in part on these figures, the International Monetary Fund (2003, p. 22) estimates that Iraq's Gross Domestic Product (GDP) fell about 22 percent in dollar terms for 2003 (Foote et al., 2004, p. 55).

Now, Iraq is in a fragile situation. It faces a difficult fiscal crunch, arising from the collapse in international oil prices coupled with persistent political and social turmoil. This situation is exacerbated by the rapid spread of COVID-19, which the country's healthcare system has limited capacity and limited fiscal buffers to contain and manage. Going forward, the economic outlook for Iraq is challenging. The collapse in international oil prices and other unfavorable global conditions, including disruptions caused by the spread of COVID-19, are expected to hit Iraq hard, leading to a 5% contraction in its economy in 2020. In the absence of significant reforms to boost private sector participation, it will be difficult to regenerate. The economy growth is projected to gradually revert to its low-base potential of 1.9-2.7% in 2021–2022. The budget rigidities, compounded over the past two years, are expected to have detrimental fiscal effects amidst weaker oil-related revenues.

At 30$ US a barrel of oil and in the absence of planned consolidation measures, the budget deficit was projected to surge to a staggering 19% of GDP by end-2020.

As a result, the GOI is expected to face a severe financing gap which could not only lead to postponing vital infrastructure projects in service delivery sectors, as well as postponing human capital programs, but also reduces the country's ability to respond to post-COVID-19 recovery needs. To sum up, Iraq is expected to face a persistent current account deficit in 2020, driven as well by lower oil prices and sticky imports. The gap is expected to be financed by the Central Bank of Iraq's reserves and State-Owned Banks, increasing the country's vulnerability in the near-term (World Bank, 2020b).

4.2 The reality of the circular economy in Iraq

The circular economy in Iraq is still in its early stages, and the projects that are established are very few, beneath standards, and most of these projects are governmental. It should be noted that there is a draft law "Waste Management at the Iraqi Parliament Council", which stresses in all its articles on the necessity of the recycling process in economic and environmental terms (Iraqi Parliament Council, 2018).

4.2.1 CE projects in Iraq

The following is an illustration of the projects that work in the sectors of the Iraqi economy.

- Basra Oil Company/Rumaila Authority has started, through the operator the field of British Petroleum (BP). To establish a center for recycling waste in the northern and southern Rumelia field, where the center was established in August 2015 and entered into actual work in March 2016. This center was designed with world-class properties, and it is the largest center in Iraq for recycling waste. It receives waste from all productive locations in the Rumelia operating field at an amount of 10 Cubic meters per day. These wastes are sorted and classified into: recyclable waste such as plastic water bottles, aluminum cans (soft drinks, iron or tin containers), and glass. As for non-recyclable waste, it is incinerated in the waste burning center, where there are two large incinerators with a burning capacity of 100 Cubic meters per day for each of them, and they are environmentally friendly. The center has warehouses for chemical waste and radioactive waste of natural origin, which is in a remote, isolated and safe area that allows entry only to persons who are authorized to enter. The center includes a yard for storing scrap. In 2018, more than 2,360 tons of waste were burned safely, along with the separation of 474 plastic bottles, 33 aluminum cans, 27 tin cans and 100 cubic meters of glass ready for future recycling (Basra Oil Company, 2016).
- The General Company for Rubber Industries and Tires, one of the subsidiaries of the Ministry of Industry and Minerals, has designed a factory for the production of bio-recycled rubber using large, wasted conventional tires with a ca-

pacity of 750 tons annually. It is now operating with a planned capacity of 400 tons annually, part of which feeds the Babylon Tire Factory and the other part is marketing to companies in the governmental sector, as well as to the private sector. The project can be considered as the first in Iraq of its kind in terms of high production capacity, modern machinery and advanced technology used in it. It contains a main mincing machine with a capacity (10 tons/hour), presses, modern machines and three production lines to produce granules and chopped Rubber with a capacity of (5 tons/hour) and rubber tiles and bumps with a capacity of (300 meters/day) in addition to, the oil production line of all kinds as well as the production of other products. "These products are used in sports stadiums, kindergartens, car garages, and in the squares, beaches and many other uses, according to demand in terms of strength, rigidity, measurements, qualities and uses", stressing at the same time that "these products are competitive with their imported counterparts, especially the Turkish product in terms of quality, high rigidity and appropriate prices". With the possibility to fully meet the needs of the local market (State Company for Tire Industry, 2016).

- Baghdad opened the first project for sorting and recycling the waste in Iraq in the Yusifiyah suburb of the Mahmudiya district with a design capacity of 200 tons per day. The cost of the project amounted to 15 million and 645 thousand dollars in 2014. The amount of waste received by the factory for the period from August 2018 to March 2019 amounted to 36,606 tons that were distributed during the 8 months. The sorted solid waste was distributed as follows (paper and cardboard, aluminum, iron, transparent champion, black plastic, colored plastic, transparent nylon, rubber, fertilizer, electronic devices), the factory suffered a loss due to high expenses and the scarcity of revenues (Mohameed and Ibraheem, 2019, pp. 394-395). This project needs technical and financial support to encourage it to achieve economic and technical efficiency.

4.2.2 CE priorities in Iraq

As mentioned before, there are priorities and elements for Iraq that must be taken into consideration when establishing circular economy projects, as follows:

- Water reuse

Fortune magazine suggests that due to water shortages, water will take place the oil in the twenty-first century (the precious commodity that determines the wealth of nations). Predictions concerning future water supplies are highly uncertain, due to the lack of adequate data, consumption patterns and technology can dramatically change the water demand, and as mentioned above climate change can have serious impacts on the hydrologic cycle, increasing evaporation rates and changing rainfall patterns (Daly and Farley, 2011, pp. 117-118).

Therefore, water reuse ought to be an important issue in Iraq, the good quality of water in the Tigris river is deteriorating as it approaches the estuary due to the pollution from urban areas prominent in the poor treatment of infrastructure (sewage) in Baghdad. The Euphrates river water quality is worse than water quality of Tigris river, it is currently suffering from a backflow of irrigation projects in Turkey and Syria. The quality of water in both the Tigris and Euphrates is detreating due to the influx of irrigated lands in Iraq and urban pollution. The quality and quantity of water entering southern Iraq from Iranian lands, is largely unknown, although it is clear that the flows are affected by the backwater irrigation flow coming from Iran. The deterioration of water quality and intense multi-source pollution has become a major threat to Iraq. The lack of an effective water monitoring network makes it difficult to take measurements to pinpoint issues of water quality and pollution. Consequently, the rehabilitation and construction of the water monitoring network have become necessary to ensure water security. Marshlands that used to be 17,000 square kilometers now it has shrunk to about 3,000 square kilometers. Water entering the Gulf Region became an issue that needs to be addressed as fisheries are an important source for food in the region. Other environmental issues to consider are the impact of water management and changing flows on migratory fish, wild species and the viability of river ecosystems across the Euphrates and Tigris basins (Frenken, 2009, pp. 66-67).

- CO2 emissions

The most prominent category of waste in the news today is CO2 emissions. Despite an impressive ability of ecosystems to absorb CO2, there is irrefutable evidence that currently, it is accumulating in the atmosphere and near-consensus in the scientific community which has already contributed to global climate change (Daly and Farley, 2011, p. 20).

Circular Economy reduces risk to supply by keeping materials in circulation and even though energy and resources will still be required for disassembly and recycling by eliminating the initial life cycle stage (extracting and processing bulk materials). Also reduces the quantity of spoil, up to 75% of embodied energy, embodied water, associated emissions, environmental and other impacts (Andrews, 2015, p. 310).

In Iraq, the average share of carbon dioxide emissions per capita in 2014 was 4.9 metric tons. Note that carbon dioxide emissions come mainly from burning fossil fuels and making cement. It includes CO2 emissions that are released during the consumption of solid, liquid and gaseous fuels and gas flaring (World Bank, 2020a). It is relatively a higher percentage compared to many other countries in the same report.

Finally, many projects have been submitted by national ministries and institutions to encourage the transition to the circular economy, and the Designated National Authority Committee (DNA) has approved the titles of 19 projects belonging to the Ministry of Industry and Minerals, announcing them as clean development projects to start registration procedures and implement them. This implementation has been delayed due to the Iraqi economy's exposure to external and internal attacks, especially the low oil prices, the lack of funding needed and the ISIS attack.

Appendix (1) that includes names and summaries of these projects (Ministery of Environment, 2016, pp. 15-17).

4.2.3 The limitations in the development of CE in Iraq

Many restrictions limit Iraq's ability to transition to the circular economy, perhaps the most prominent of which are the following:

- Corruption

Corruption results in an increase of production cost, a decrease of national and foreign investment, inefficient allocation of national sources, increase of inequality and poverty in the society and uncertainty in decision making. In all countries, corruption is considered harmful to government efficiency. It limits budgetary balance, lowers the efficiency of government spending and disturbs the budget allocation among individual budgetary functions. These disadvantages present transmission mechanisms of unfavorable effects of corruption on economic growth.

Government spending is one of transmission channels of corruption impact on economic growth that is currently ignored, especially the allocation of government spending. Regarding the growth of public expenditures in the few decades, the growing significance of this channel can be predicted and the attention to it is justified (Jajkowicz and Drobiszová, 2015, p. 1251).

According to the Transparency International report, Iraq's score was 18, which means that Iraq falls within the first quarter of the most corrupt countries among the 180 countries of the world that were included in the report, and it ranked 168 among the least integrity countries among the 180 countries of the world that were included in the report (Transparency International, 2019, p. 10).

- Spending priorities

In 2014, the double attacks of the ISIS invasion and the collapse in oil prices had a devastating effect on the economy as government finances were crushed by soaring expenses and plummeting revenues. Resources for maintaining basic services were diverted to military spending, the government was forced to make dramatic cuts. The years of conflict stretched the country's capacity to function to the extreme. Including Iraq's ability to implement proposed projects related to the circular economy (Tabaqchali, 2017, p. 5).

4.3 Transition to circular economy in Iraq, fiscal and monetary policy between stimulus and financing

4.3.1 Proposed procedures for fiscal and government policy in Iraq

Fiscal policy can be used as direct tools for the Iraqi central government to play the motivational role and financing function to establish a circular economy, so it is possible to make some proposals, including:

- The Iraqi government must develop a series of laws and regulations. For example, "circular economy promotion law" or "regulation of waste", etc.
- Investing in some circular economy projects with the participation of the private sector to encourage domestic and foreign private investment.

- Tax exemptions on business profits in new investments in the circular economy for a limited period, such as one year, to encourage investors to invest in such projects.
- Exemption partially or entirely from indirect taxes such as customs fees in all activities related to the project of the circular economy.
- Exempting retained profits from the project's circular activities from taxes if they were invested in establishing new projects or expanding existing ones.
- Providing investment (capital) subsidies, especially to small enterprises wishing to invest in circular economy activities.
- Increasing government spending on raising awareness of benefits of circular economy economically and environmentally, as well as establishing special industrial zones for circular projects in which infrastructure is provided by roads, transportation and fundamental services.
- The Iraqi government must take into his consideration development of citizens' behavior regarding the separation of valuables, their cultural background concerning waste management, and social norms must be taken into account when planning collection schemes. Convenient access to collection systems is essential. Citizens must become accustomed to these systems; long-term awareness-raising helps to optimize the successful collection of recyclables (Friege, 2017, p. 11). Especially if we know that Iraq's production of Biofuels and waste reached 47 kilotons of oil equivalent (ktoe) in 2017 (International Energy Agency, 2017).
- Impose Carbon taxes by the Iraqi government that charges on the carbon content of fossil fuels. Their principal rationale is that they are generally an effective tool for meeting domestic emission mitigation commitments. These taxes increase the prices of fossil fuels, electricity, general consumer products and lower prices for fuel producers, promotion to switch to lower-carbon fuels in power generation (Circular Economy) conserving on energy use and shifting to cleaner vehicles, among other things. A tax of 20$ a ton on CO_2 emissions in 2030 would typically increase prices for coal, electricity, and gasoline by about (100%, 25% and 10 %) respectively. Carbon taxes also provide a clear incentive for redirecting energy investment toward low-carbon technologies like renewable power plants.

4.3.2 Proposed strategies for monetary policy in Iraq

In this research, the status of the Central Bank is analyzed and some suggestions about the measures will be provided, that can be followed to stimulate the establishment of the circular economy in Iraq, as well as providing some financial resources for it.

- Special Drawing Rights (SDRs) and Gold

The Central Bank of Iraq can restructure its assets and convert its investments from private drawing rights and gold into financial assets that encourage circular economy projects, for example giving the government an exception to Article 26 of the Central Bank of Iraq Law No. 56 of 2004 which states "not to grant any direct or Indirect credits to the government to any public body or any state-owned entity” (Central Bank of Iraq, 2004, p. 21). The exception includes the direct purchase of governmental green or circular bonds only, to indicate the need to finance the circular economy projects, which will motivate the government to seriously establish many targeted projects (see Appendix 1 of many projects need financing). It is possible that these circular bonds have zero interest to stimulate the transition to a circular economy at zero financing cost for the government after studying all government projects and choosing the best ones economically and this can be called Circular Quantitative Easing (Circular QE) or Green Quantitative Easing (Green QE).

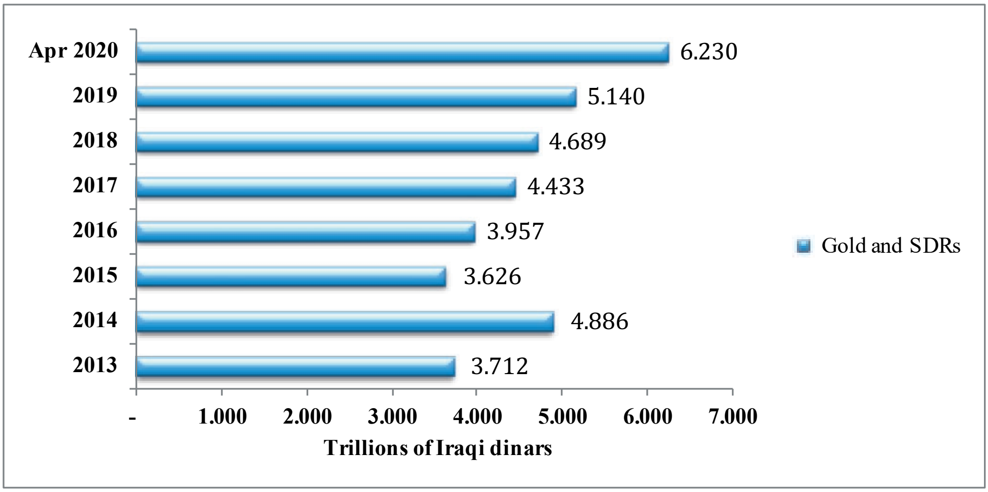
At the same time, the Central Bank of Iraq will have environmental goals to achieve like most central banks in the world.

Graphic 1 shows the development of the Central Bank of Iraq assets from gold and special drawing rights for the period 2013-2020, that the bank has approximately 6 trillion Iraqi dinars until April 2020, approximately equal to 5 $ billion (Central Bank of Iraq, 2020). These assets have developed significantly in recent years, where a certain percentage of them can be directed to circular financial assets that support the national economy and have future implications on the size of the national GDP.

- Circular certificates (CC)

The creation of Circular Certificates (CC) issued by the Central Bank of Iraq that would allow circular economy projects, developers, to repay a portion of their loans to commercial banks using these certificates gained through established their projects which have economic and environmental goals after assessing their feasibility by the Central Bank of Iraq.

Graphic 1. Central Bank of Iraq assets from gold and Special Drawing Rights (SDRs).



Source: CBI / Research & Statistics Dept. / Monetary & Financial statistics Division.

When the Central Bank issues such certificates to investors in the circular sector, this will lead to achieving many results:

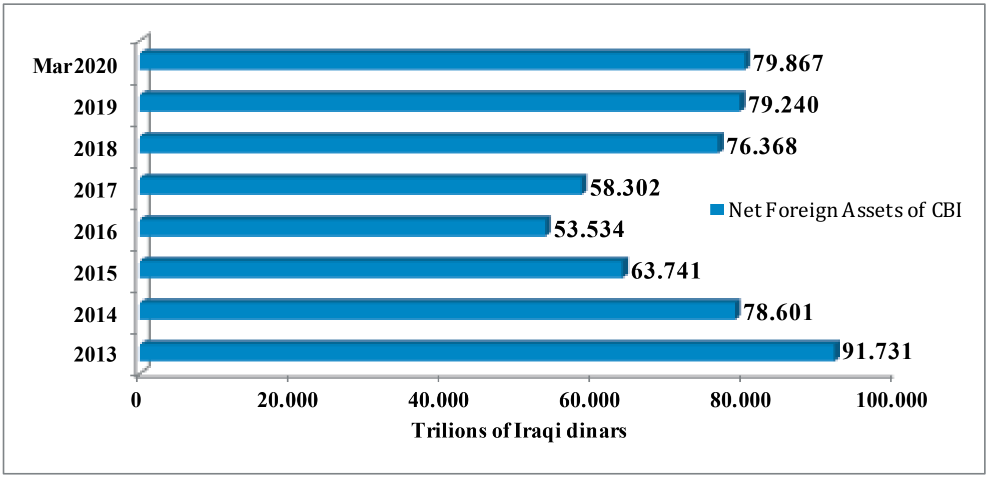
- Achieving the primary goal, which is to stimulate and encourage the establishment of circular economy projects.
- Encouraging investors from inside and outside Iraq to invest in circular projects and, as a result, diversify the Iraqi economy.
- Providing a new source for the flow of foreign reserves (foreign currency) and not relying solely on foreign currency resulting from exporting the oil.
- Development of the Iraq Stock Exchange.
- This needs to build relationships between the Central Bank of Iraq with other central banks in the world and set up auctions to issue circular or green certificates.
- Encourage the banking sector to create circular credit (or Green credit)
- The Central Bank of Iraq can encourage the banking sector (commercial or specialized banks) to increase the credit granted to circular economy projects thus provide funding and incentives for investors in this sector to increase their investments. Knowing that the number of banks operating in Iraq is 71 banks, including foreign banks operating in Iraq with total assets amounting to 124 trillion Iraqi dinars is equivalent to 110 $ billion (Central Bank of Iraq, 2018, p. 117). Some tools must be applied by the central bank to increase circular credit by using some quantitative tools such as reducing the re-discount rate for the banks that finance the targeted circular projects or follow certain specific tools such as granting loans to the banks with interest rates close to zero to encourage circular loans. In return asking them for a moral persuading method to finance circular activities to stimulate the transition to the circular economy.
- The initiative to support circular economy projects.

The Central Bank of Iraq can adopt an initiative to support circular economy projects such as the 1 trillion initiative launched by the Central Bank in 2019 to support small and medium enterprises with the participation of government and private banks (Central Bank of Iraq, 2019). The effect of this initiative is to give a general impression to banks and investors that the Central Bank of Iraq supports the circular economy projects directly. In addition to stimulating the transition to a circular economy and providing sufficient financing resources, this will lead to achieving economic growth, diversifying and providing job opportunities. It is possible to invest some foreign reserves that The Central Bank of Iraq has developed well in the recent period (Graphic 2) to finance this initiative and to be a major initiative at the level of Iraq.

5. Results and Dissection

Iraq possesses the basic elements for establishing the activity associated with the circular economy and its types, especially those related to fossil production waste, as it is from the oil-producing countries. From data collection, it is clear that the steps to transition to a circular economy have not yet started but there are

Graphic 2. Net Foreign Assets of Central Bank of Iraq.



Source: CBI / Research & Statistics Dept. / Monetary & Financial statistics Division.

very few projects that have been mentioned and all of them need to develop and grow with the rest of the economic sectors.

There are many projects submitted by the ministries with the efforts of the economic authorities in Iraq to set up 19 projects that are awaiting approval by the government since 2016 (Appendix 1) and their activities fall directly within the activities of the circular economy (Ministery of Environment, 2016, pp. 15-17), they were not implemented either because of the lack of financing resources or the security conditions that went through Iraq in recent years. It should be noted that most of these projects represent the public sector, and there is no essential role for the private sector that the government must encourage him to invest in such projects even if the starting point is the establishment of linked projects between the public and private sectors.

As for the monetary and fiscal policy in Iraq that were focused on because they represent the main tools of economic policy that did not play the role required to stimulate and finance circular projects. These two policies are still in most aspects with traditional methods and goals, several proposals were given as unconventional policies and procedures, it was applied to will encourage investors to invest in the circular projects.

The Iraqi government should take real steps towards setting up investment projects in circular activities or encouraging their establishment by the private sector, as they have large dual effects on the Iraqi economy. The first one being diversifying the Iraqi economy, move the economic cycle and drive towards economic growth, which means low unemployment, the second effect is to achieve the environmental goal and provide a good quality of life for citizens who suffered from high pollution rates as a result of wars that they went through.

Therefore, in the first step, the Iraqi government must stimulate and finance the transition to a circular economy through its fiscal tools and monetary policy strategy, and then there will be a basis for creating a circular economy that attracts the private sector to invest in its projects as a second step.

6. Conclusions

- Iraq is characterized by an abundance of natural and human resources, but this abundance was not invested, instead of that it was neglected, as it was possible to invest the waste of water, energy, other resources, especially as Iraqi cities suffer a lot from neglecting. For example, Basra is one of the largest Iraqi cities in terms of oil production, so it is clear that the size of cancerous diseases people of this city suffer from as a result of the combustion of gas accompanying the production of oil. Combustion of gas is a cause of environmental pollution and it also represents a waste of an important source of energy sources, it is about the lack of services provided to the city's residents, which made the Iraqi government pay more attention by providing desalinated drinking water since the drinking water provided to them is salty water, as well as the necessity of providing hospitals and medicines to treat many diseases. The authorities (the governor) think seriously about getting rid of the residents from the waste that filled the streets, then taking care of the population and the environment.
- There are no real government programs that aim to stimulate circular economy projects despite their great benefits at the economic and social levels, both fiscal and monetary policy has not taken a real role in achieving this goal.
- There is a delay in the legislative side in adopting laws that contribute to achieving the goal of adopting circular projects, such as "the Clean Energy Law" or "the Circular Investment Law" or other laws that may represent a program that the government is obligated to abide by.
- Financial and administrative corruption, as well as the fight against terrorism, are two major obstacles to implementing and financing project proposals for recycling in Iraq.

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Appendix 1. CE Projects Waiting for Approval

1. Automatic burning systems for brick factories: proposed by the General Directorate of Industrial Development. Replacement of burning systems for brick factories belonging to the private sector, amounting to 650 factories, with various production capacity and green, modern systems achieve a 40% reduction in greenhouse gas emissions and heat recycling of chimneys, which leads to an increase in the efficiency of the current factories in using less fuel and more quality products.
2. Solar heater project: proposed by the Research and Development Authority. Creating a production line for the solar water heater industry with a production capacity (3000 heaters per year) as a first stage and then increase production capacity to (100,000 heaters/year) as a second stage after the success of the first stage and increasing the awareness of the use of the solar heater and the accompanying energy rationalization. The fact that the heater is one of the most energy-consuming home appliances, and the consequence of this rationalization is to reduce greenhouse gas emissions resulting from the electric power generation that the normal heater works on.
3. Lime cement project: proposed by the General Company for Iraqi Cement. Product lime cement with special specifications that is using in the construction works depends on increasing the heap compared to the material of carnacle and alumina i.e. increasing the cement production with the same energy used for the current burning.
4. Rehabilitation project for Basra Fertilizers Factory (NAMAs): proposed by the General Fertilizer Industry Company. It is a project to rehabilitate Basra Fer-

tilizer Factory in a way that has increased the efficiency of the factory as the product has increased with the rationalization of energy as well as the use of environmentally friendly chimneys and heat recycling. The associated qualification is to reduce greenhouse gas emissions and a significant reduction in carbon and to reduction in other equivalent gases.

5. Electrical Power Improvement Factor Project (NAMAs): proposed by the Communications and Capacity Equipment Company. It is a project that is being implemented by the Communications and Capacity Equipment Company, the Ministry of Electricity and some formations of the Ministry of Industry, where the power improvement factor is added to the energy sources of these buildings, which leads to the exploitation of wasted energy that reaches 25% of the equipped energy and this leads to rationalization In the consumption of electricity, with 25% reduction in carbon.

6. Electrical power improvement coefficient project (CDM): create a project to add power improvement factories to electrical power supplies to reduce waste and reuse of currently lost energies to increase resource efficiency by 25%, and the Ministry of Industry hopes to support this project by registering it within CDM projects.

7. Tire recycling project: proposed by the General Company for Engineering Support. It is a project to reuse tires through cut it and grind it to be valid for flooring, sports stadiums and other uses instead of burning them and causing greenhouse gases emissions.

8. Hydrogen cell generator project: proposed by Al-Zawra State Company. It is an electric power production project using a hydrogen cell. It supplies water and methanol and releases oxygen instead of greenhouse gases that accompany the generation of electricity from sources currently used.

9. RO Water Purification and filtering System Project: proposed by the Research and Development Authority. It is to create a production line for the manufacture of solar powered water purification and filtering systems and the consequent non-use of traditional electric energies and the resulting greenhouse gas emissions.

10. Photoelectric energy project for the Energy Research Center building proposed by R&D Authority is to provide the building of the Renewable Energy Research Center with electric energy using optical cells and the accompanying use of smart energy consumption systems and economic and smart lighting systems and the accompanying project of the lack of greenhouse gas emissions accompanying the generation of this energy, even if its generation depends on traditional methods.

11. Waste recycling project proposed by Al-Rasheed Compact Company: works to recycle waste with a production capacity of 1000 tons for every factory and twenty recycling factories distributed to all governorates, and these capacities will be increased in the future. As is well known, waste recycling is one of the most important global reduction projects, as it prevents leakage methane and other greenhouse gases for the atmosphere, as well as using the gases and materials emitted from recycling process to produce clean energies.

12. Hydroelectric Welding Machine Project proposed by the General Company for Hydraulic Industries: it is to create a production line for the welding machine that is powered by hydroelectric energy instead of electrical energy. As is well known, the global consumption of electrical energy for these machines produces gases in large quantities if these machines continue to operate with electric energy.

13. Submersible pumps project proposed by the General Engineering Support Company: is a project to manufacture water pumps of various types, capacities and horsepower capabilities powered by solar energy, and in this project double benefit can be achieved by reducing emissions and adapting to climate change in terms of not using electricity or fuel-powered pumps that are accompanied by a large emission of gases as well as the ability to operate pumps in remote areas and away from energy sources, which would allow it to work on cultivating new areas, it might add green spaces and air-purifying belts to surround cities and reduce desert areas.

14. Solar barley cultivation project (adaptation), proposed by the General Company for Hydraulic Industries: the project is to produce high-quality animal feed through the cultivation and cultivation of barley in multi-shelves incubators and air-conditioned layers with a specific moisture content and standard heat and the use of solar panels in generating the required for these incubators and production will be during a period not exceeding 10 days only and without emissions of greenhouse gases contrary to the way of cultivating them in the ground in the traditional way which are accompanied by the exploitation of lands with vast areas, longer times and wastage of water, in addition to the greenhouse gas emissions that are caused by tillage and cultivation.

15. Tissue buds project (adaptation) proposed by the private sector: a project that aims to multiply palm seedlings and buds of economic plants such as olives and citrus fruits in a laboratory by adopting tissue reproduction and cultivation in a standard laboratory setting, the project's productivity reaches half a million buds annually with high-quality specifications that are resistant to the external environment and disease-resistant as these distinctive shoots with the required specifications are replanted in regular lands and each according to the region's need and the project works to re-develop the Iraqi agricultural activity The resulting purification of the climate, the consumption of CO2 gas and the release of O2 gas.

16. Project for the production of general lighting fixtures (LED) proposed by the General Electric and Electronic Industries Company: is a project to produce lighting compositions working with LED, with production capacity meets the need for the local market, and this project is accompanied by a very large rationalization of electrical energy in the event that these lamps are used in place of the traditional high-consumption light bulbs currently used.

17. Scrap metal recycling project proposed by the General Engineering Support Company: it is a project that aims to collect scraps of military waste and cars and recycle them to produce iron clips, plastic granules and other by-products, and it is considered one of the most important projects to preserve the environment from iron waste and a great rationalization of energy in the event of recycling instead of obtaining primary materials through their production from natural sources.

18. Carbon Dioxide Retention Project proposed by a ministerial committee chaired by the Ministry of Industry and the membership of the ministries of oil, health and electricity: it is a joint strategic project between the four ministries and has prepared a full technical and economic feasibility study aimed at separating and capturing carbon dioxide gas, liquefying, transporting and injecting it in geological structures in Basra governorate to improve the viscosity of oil and get rid of CO2 gas from power plants, iron and steel, petrochemical, paper and fertilizers factories, which are very large quantities in the event of retention, a significant reduction in emissions is achieved, in addition to reducing the use of water for injection associated with the production of oil, so this project is one of the most promising projects and achieve the largest quantities of desired reduction.

19. Project for the production of building sections using palm waste – (palm –fiber polymers (pfp)) proposed by the private sector: it is a multi-benefit project that works on the exploitation of palm waste and its accompanying areas to clean the lands and increase the encouragement of agriculture and not to burn waste by random methods or neglecting it and its decomposition and emission of gases from it, in addition to the manufacture of construction sections of high thermal insulation and quality works to adapt to the rise in the temperature of the land and also will reduce the use of other constructional sections such as blocks and bricks and the accompanying production of energy consumption and greenhouse gas emissions, as well as to preserve the coolness of the buildings that are built from them, which reduces energy consumption for refrigeration, so this project is one of the most important modern private sector projects with indirect benefits in the field of emission reduction of gases greenhouse and adaptation to climate change (Ministery of Environment, 2016, pp. 15-17).

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Short-Term City Dynamics: effects and Proposals before the Covid-19 Pandemic[1]

Sharing platforms have been changing urban balances and triggering historical cities' transformation from a structural, economic, and social perspective before the Covid-19 Pandemic.
In particular, Airbnb influences urban space, production through physical impacts and the tendency to mystify places, appealing to authenticity and experiential tourism. New images of reality, mediated by the platform, constitute the symbolic production of the city's tourist palatability, which is intertwined with new uses and the exasperation of the consumption of a part of the cultural heritage. The research aims to structure a hybrid methodological approach combining investigation and assessment for identifying and understanding the impacts of touristification and over-tourism on the urban dimension and develop intervention strategies consistent with the Circular Economy perspective. In Southern Italy, Naples City is chosen as a case study and field test.

1. Introduction

The touristification concept defines the whole of urban spaces transformation processes aiming to shape the city exclusively in terms of attractiveness for the ordinary tourist. Some authors, indeed, define touristification as the transformation of residential neighbourhoods to tourism precincts (Gurran et al., 2020; Sequera and Nofre, 2018). Other authors remark the cosmopolitan features of the cities affected by this process that turns urban spaces and neighbourhoods into leisure playgrounds with substantial impacts on residents (Lim and Bouchon, 2017). In this perspective, Farkic correlates touristification with consumption of dystopian places, where commercialisation and museification of the city are related to the touristic experience (Farkic, 2020).

According to Gutiérrez et al. (2017), peer-to-peer (P2P) accommodation phenomenon, fostered by AirBnb, HomeAway, Wimdu, etc., has been leading to touristification of historic downtown due to high availability of empty apartments even more than hotspots density. At the same time, the significant social impact of historic downtown touristification has been considered as the displacement of lower-income residents due to increasing home market values

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(Atkinson et al., 2011; Hyra, 2016; Gurran et al., 2020; Miller, 2014; Rouwendal et al., 2018).

Therefore, these typologies of changes are unable to restore identity-related features either for the famous tourist towns or the towns searching for a new image as "tourist destination" (Marchi, 2012). On the downside, they deplete the places meaning and profoundly transform cities image by the homogenisation in terms of everyday needs that are strictly related to the uses (e.g. metro station, pub, street food, souvenirs shops). In more severe cases, a fake has been generated by stereotyping realities for use and consumption of tourists (e.g. fake clothes hanging in the Spanish quarters of Naples, in Italy, or coloured flags that decorate them). Furthermore, the unsustainability of tourism has been already revealed by Hollenhorst et al. (2014) when they unmasked the image of tourism as a false embodiment of sustainability since it is one of the most carbon-emitter industries and resource depletion factor.

According to some studies, indeed, the tourism sector would be responsible for the emission of 4.5 Gigaton of CO_2 in 2013, corresponding to the 8% of global carbon footprint and increasing four times more than the previous year estimation (Lenzen et al., 2018). In this perspective, Andersen (2007) has highlighted the contribution of environmental economics (Pearce and Turner 1990) addressed to measure negative externalities to market prices in terms of ecological charges to include within the mutual transactions among economic stakeholders.

The relationships between tourism and SDGs targets have been remarked by the "1st Research Conference on Tourism and the SDGs" (UNWTO, 2019), which has highlighted positive and negative impacts of tourism in terms of sustainability. The primary outcome of the Conference mentioned above has highlighted strong relationships, specifically with three objectives:

- SDG 8 - "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all";
- SDG 12 - "Ensure sustainable consumption and production patterns";
- SDG 14 - "Conserve and sustainably use the oceans, seas and marine resources for sustainable development".

Nevertheless, tourism as economic development driver can be meaningful, the relevant force also for: creating new job opportunities (1); shifting towards sustainable agriculture supply chain (2); re-investing tourism taxes for health and care services (3), promoting inclusiveness, gender empowerment through income generation, and reducing inequalities through local population engagement (4,5,10,16), boosting investment for water and sanitation utilities and renewable energy (6,7), improving local private and public infrastructure with particular attention to cultural and environmental heritage (9, 11), contributing to climate change mitigation and/or acceleration in terms of people awareness enhancement (13), preserving biodiversity and nature as main opportunities to enrich tourist experience (15), and reinforcing private/public partnerships (17). Therefore, the tourism industry has great potential to contribute to the achievement of the SDGs, as the third-largest socio-economic activity in the EU. Tourism can activate Circular Economy (CE) processes, consistent with the concept of "sustainable tourism" and link the different dimensions (economic, social, cultural and environmental) contributing to their mutual improvement (Fusco Girard and Nocca, 2017).

The risk is that every future design, policy, and planning are going to undergo a process of consumer display, trivialising local cultural resources and identity-related features up to stereotyping cities. Touristification is inextricably connected to overtourism neologism which means tourist overcrowding. In a nutshell, the overtourism occurs when the demand outreaches the available supply, i.e. when a destination has been stormed, and the tourist flows exceed the carrying capacity of places. According to Tomaselli (2018), tourism is an extractive industry, precisely like the oil industry. It does not produce goods, but it aims to mine values from "added value" treasure trove tills to deprive it of real life forms. In this meaning, the primitive nature of tourism has to be understood to manage it better.

Within an open-ended system, indeed, the extraction of matter and energy for the economy bound to tourism activities determines entropy increasing (Georgescu-Roegen, 1971). It is the reason why a Circular Economy (CE) model, defined by Ellen Macarthur Foundation (2013, 2017) that aims to close the loop of resource use and waste residuals, has to be adopted to face tourism flows and demands of citizens living in overcrowded cities. According to Rodríguez et al. (2020), circular tourism implies a model in which each tourism actor (tourist, destination management organisations, suppliers, and resident population) assumes an eco-friendly approach, based on the principle of "closing the life cycle" of products, services, waste, materials, water and energy, and reconsidering waste as a new resource for the city-system.

Moreover, the excessive growth of tourism has been supporting by the emergence of P2P accommodation phenomenon which inaugurates the season of the so-called "platform capitalism" (Celata, 2018; Kenney and Zysman, 2016; Langley and Leyshon, 2017; Olma, 2014; Srnicek, 2017; Stergiou and Farmaki, 2019). The *airification* of cities, at once, has been strengthening the ability of these platforms - which act like real political stakeholders - to engage and influence users into a discussion about the regulation of their activities, unbalancing the precarious real estate market of cities (Parisi, 2018; Picascia et al., 2017).

The "platform capitalism" has allowed the homeowners to become self-made entrepreneurs since it will enable them to enhance a waste building heritage, which would be unattractive for the ordinary market. This practice highlights the existence of an "interstitial income" which can be improved through short-term rent. In this direction, searching balance between places and tourist flows spaces leads necessarily to the formulation of collaborative and circular strategies. Indeed, circular and sustainable tourism does not refer exclusively to green tourism which aims to limit the consumption and waste of non-renewable energy sources but is also connected to the practices of recovery, reuse, requalification, and of enhancement and regeneration of cultural heritage (Nocca, 2017). The promotion of the CE principles in the rehabilitation and conservation of cultural heritage is essential for defining innovative strategies, oriented to a slow tourism model and culture-led regeneration projects (Rodríguez et al., 2020).

Therefore, a hybrid company consisting of stakeholders' coalitions, which enable bottom-up processes and promote the company as a vehicle for new social values and models of wealth, has its foundation (Venturi and Zandonai, 2016; Zamagni, 2018). The proposed policy has its roots in the awareness that the CE identifies both new consumption models (such as sharing and bartering of goods) and new business models (including reuse, regeneration, eco-design), which are assuming a predominant role in the current socio-economic scene (Vargas-Sánchez, 2018), and are able to trigger and stimulate circular flows, aiming to conciliate the tourism sector and sustainable local resource management.

The research aims to investigate the touristification and overtourism phenomena which involve Naples historic downtown, in the South of Italy. The effects on the short-term city dynamics, concerning the ordinary real-estate market, support to develop an intervention strategy for the mitigation of negative tourism effects and to determine a more sustainable scenario. The paper develops, in Section 2, methods and tools, describing the methodological process and its articulation; Section 3 introduces the case study of Naples; Section 4 describes data processing and assessment, and Section 5 presents discussion and conclusions with a proposal of policy strategy for the selected case study to implement CE principles.

2. Methods and tools

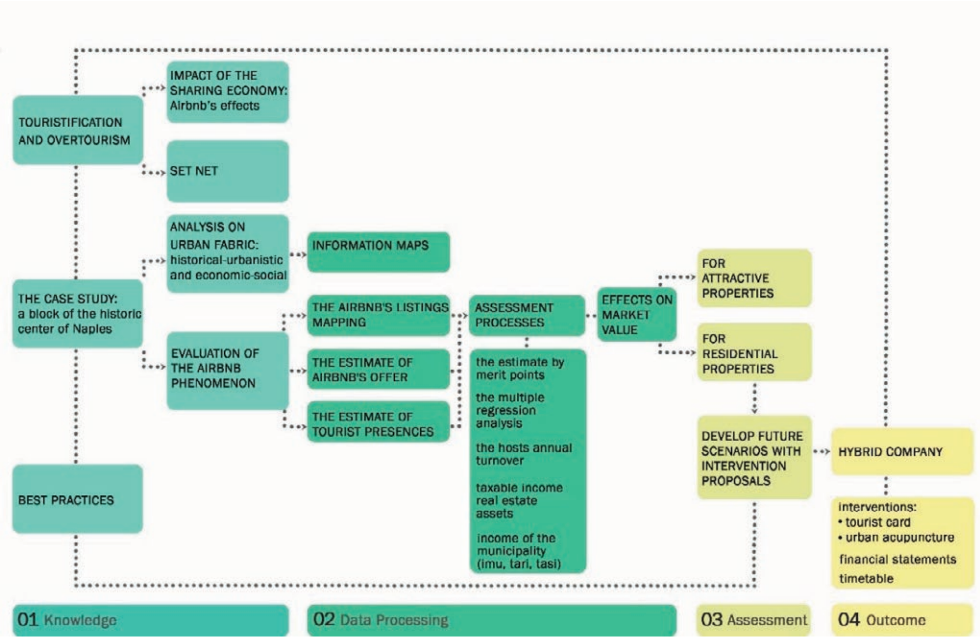
The methodology has been structured into four main steps (Figure 1): Knowledge; Data Processing; Assessment; Outcome. The exploratory phase of knowledge has been aimed at the investigation of meaning and effects assumed by touristification and overtourism in different cities of the world. The comparison has been focused on the impact of Airbnb in accelerating the tourist saturation process of the observed cities. In any case, the effects tend to manifest themselves in different ways and times, depending on the city's propensity to lose its authenticity in view of turning to the tourist destination.

The capacity to resist, more or less for a long time, against the transformations required by touristification, lies in the historical-urban and economic-social features that make up the city under observation. The graphic representation of these features allows for obtaining maps of georeferenced information.

Investigating the Airbnb phenomenon and mapping the listings, together with the estimate of Airbnb offer weight in terms of tourist presences, means operationalising a hybrid methodology which involves IT skills and on-field survey. Accurately, the census of ads referring to the case study has been performed through data mining from a web site technique defined as "web-scraping". Data extraction, led on a monthly basis for one year of observation, has allowed the subsequent development of the database. The list from Airbnb scraping has been compared with a survey from Insideairbnb.com platform.

The following methodological process has pursued the aim of evaluating the economic gain in renting property without regular lease through the Airbnb platform and assessing the interstitial rent generated during the year of observation:

Figure 1. The methodological framework.



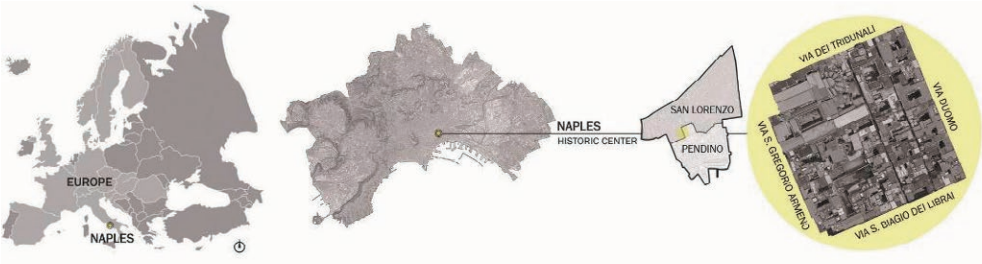
1. the assessment by merit points method and the unitary normal value for the determination of the weighted average of the market value of the observed properties;
2. the multiple regression analysis to highlight the most influential variables in determining the observed average market value;
3. the assessment of the hosts annual turnover for the comparison with the taxable income of real-estate properties and the income collected by the municipality through services taxes.

The hybrid implementation of different methods allowed us to gather the results of the investigation through incremental steps. The assessment – along with the analysis of best practices – has been useful to identify a suitable policy for the sustainable development of local resources, able to activate regenerative processes consistent with the CE principles. The policy strategy has been compared with the current scenario to produce outputs which consist in both physical interventions on assets, both intangible ones, at several levels, e.g. the economic development, the communication, the interaction between different stakeholders, till up the transformation and enhancement of urban space.

3. The case study

The assessment has been elaborated on a block of the Naples historic downtown. The selected area is located in a central position between San Lorenzo and

Figure 2. The study area.



Pendino neighbourhoods (Figure 2). The focus area intercepts the streets of San Biagio dei Librai and Tribunali – known as *decumani* of the ancient Greek-Roman urban fabric – and Duomo and San Gregorio Armeno streets, which are the longitudinal axes referred to as *cardines.*

The selected block is highly stratified, and it dates back to Greek epoch since it preserves a large part of the orthogonal layout. Since the nineteenth century, the most evident transformations can be highlighted by the urban plan, as a result of the post-unitary restoration plan of 1868 which led to the enlargement of Duomo street and renovation of several buildings' facades (Ferraro, 2002). The following changes mainly concern structural adaptation and typological adjustment because of the housing emergency (Figure 3).

As mentioned above, the hybrid methodology for assessing Airbnb's effects has been performed with the monthly extraction of data through web-scraping into the range from June 2018 to May 2019. This step has been led through the open-source software "Airbnb Data Collection" (https://github.com/tomslee/airbnb-data-collection). The used tools are the followings:

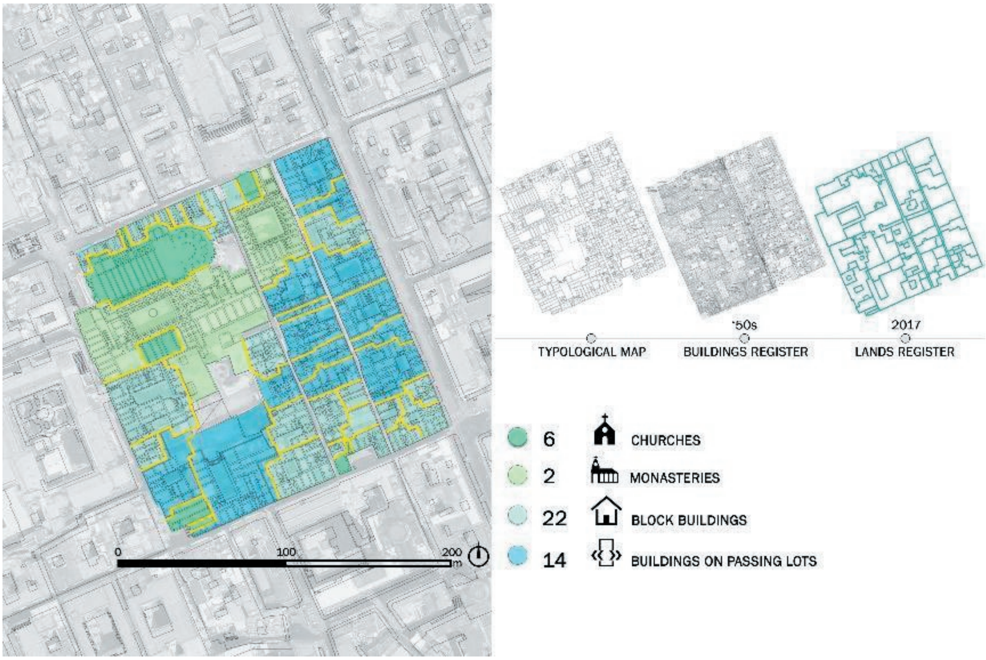
1. Python script to extract information concerning the accommodations on the Airbnb website;
2. PostgreSQL database to store data;
3. Graphic editor PgAdmin4 to create queries (management, modification and consultation of the DB).

At the same time, data mining procedure, therefore, can be summarised into four main steps:

1. Identification of the geographical search area for accommodations;
2. Choice of survey method among neighbourhoods, bounding box or zip code methods;
3. Choice of the survey to implement into Python script;
4. Creation of tables (e.g. "search_area", "survey", etc.), identified by the corresponding ID.

The bounding box has been chosen as the preferred detection method for data extraction since it allows to overcome the uncertainty of the street addresses of the individual listings. The extracted data have been converted into .cvs format

Figure 3. Analysis of the urban fabric.



to enable the subsequent structuring of the dataset. Through this analysis, it has been possible:

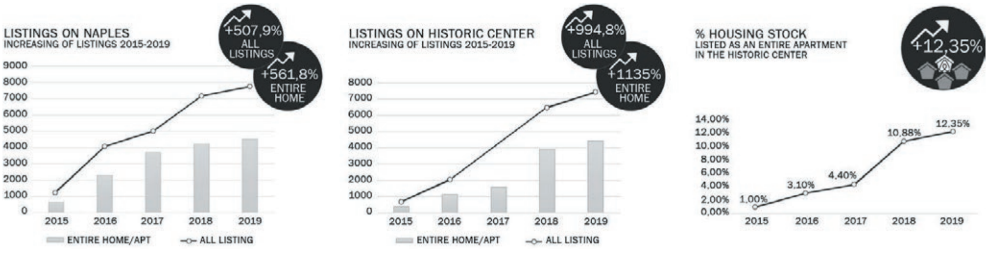
- detecting the available structures and the beds offer;
- assessing of tourists' presences linked to Airbnb;
- estimating of currency revenue;
- comparing the prevalence of Airbnb offers with the overall traditional accommodation.

The listings mapping has been compared with on-field data survey, to join the available turnover data of the hosts to the cadastral data, therefore to the consistency of the properties. Data, emerging from the assessment of the hosts annual turnover, have been compared with the delta parameter determined between the captured income by the platform and the taxation of properties intended for rental on Airbnb, as well as the delta parameter obtained from the taxable income of properties. Through the carried out analysis, it was possible to evaluate the effects of tourism on residents and, thus, develop future scenarios with intervention proposals.

4. Data processing and assessment

The applied methodology has highlighted the transformation process of the socio-economic composition of the observed block and the use change of the pre-

Figure 4. Analysis of the Airbnb phenomenon: trends related to listings on Naples and historic centre, and housing stock.



viously residential properties. The observation and detection period for data collection is before the COVID-19 emergency and takes into account the dynamics that were not affected by the pandemic.

In Naples downtown, indeed, between 2015 and 2019, an increase of more than 900% in the offer of accommodation on Airbnb can be detected (Figure 4). A phenomenon that could be conceived as airification city has been taking place, in conflict with living and CE principles.

By combining the available research methodologies, the final mapping of extra-hotel accommodations "made in Airbnb" has been drawn (Figure 5). The obtained data detect the presence of 39 entire apartments, 37 private rooms and 0 shared rooms, for a total of 310 beds.

The offer on Airbnb exceeds the traditional and non-traditional competition since, in the study area, there are only eighteen B&Bs and one hotel. Among the 37 private rooms which are available on Airbnb, 36 derive by the division of the entire apartment on several separate ads; therefore, the number of whole apartments for rent on the platform is more significant than what emerges from web-scraping. The analysis of the ads reveals a total of 41 real-estate units on the platform. The data highlights that 99% of the total ads refers to an entire apartment, where the host does not reside, and it is no longer a source of income integration, but a small business. The presence of 38% of hosts that publish multiple ads

Figure 5. Maps of extra-hotel accommodations "made in Airbnb".

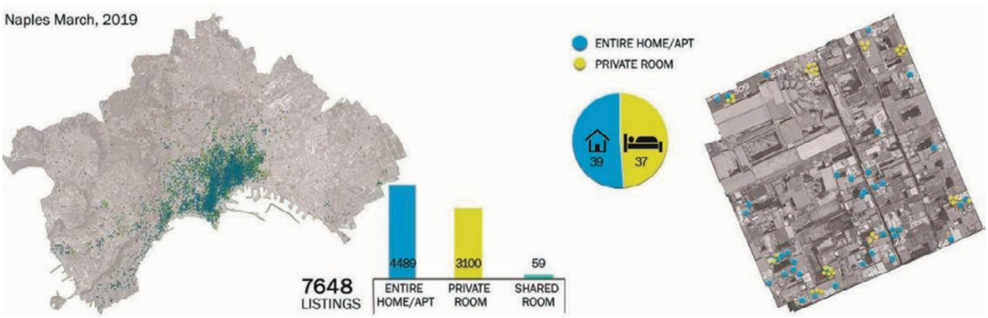


Figure 6. Residential real estate and identification of real estate susceptible to turbo-valorisation.

also notices the growing trend to value the second home on the short-term rental market.

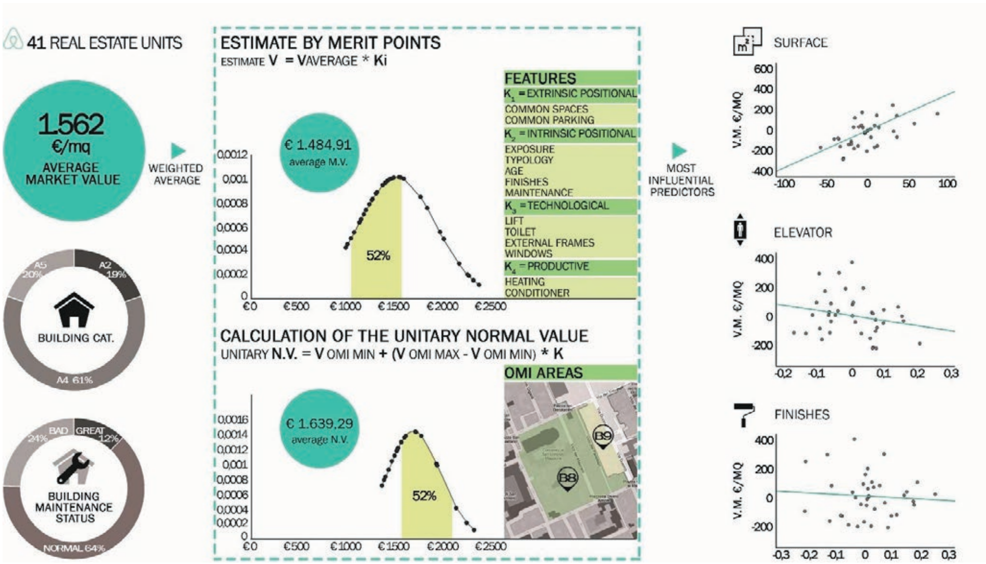
By crossing the cadastral data with the average market values, indeed, it has been observed that 62% of residential real-estate units have been affected by a turbo-valorisation process (Figure 6).

Within the analysed area, no high concentration of properties owned by a single host can be noticed; therefore, the management of properties by companies has been excluded. Nowadays, a kind of human dimension has been enduring; nevertheless, it risks disappearing in the face of economic gains, as detailed below. Observing focus area data through scraping technique, it highlights that tourism flow overbooks the available accommodation especially in conjunction with annual festivities, e.g. the Bridge of the Dead, Christmas, Carnival, Easter time, decreasing in summer months. The overall trend in figure 6 highlights a lack of gradual "seasonally adjust" of the phenomenon.

Among 41 real estate units, located into the analysed cadastral registries and featured on Airbnb listings, it emerges that: 61% of public housing (A4), 20% of ultra-popular housing (A5), and 19% of civilian housing (A2). The on-field observation, however, detects a mainly average maintenance status of the buildings – around 64% – and just 12% of buildings with an excellent maintenance status. The average market value of these real-estate units measures 1,562 €/sqm, and it has been calculated as a weighted average between the value inferred from the summary estimate by merit points method and the calculation of the normal unit value (Figure 7).

All the features of the observed market value, instead, have been elicited through multiple regression analysis (Benjamin et al. 2004; Curto, 1993; Dell, 2017;

Figure 7. Assessment of the real estate units: values and influential predictors.



Isakson, 1998; Isakson, 2001; Lisini, 2007; Manganelli and Tajani, 2009; Rosato and Simonotti, 1988).

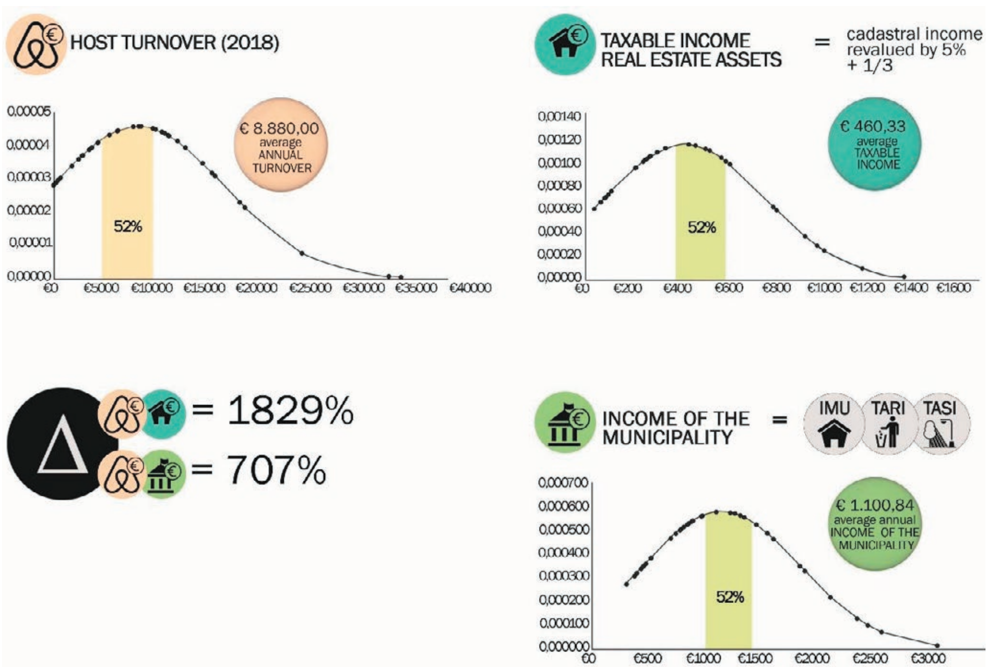
In this case study, the dependent variable Y is the Market Value (MV). At the same time, the predictors consist of 42 indicators at two main scales of investigation referring to: (i) the analysed property and (ii) the urban and socio-economic context. The SPSS software, provided by IBM, has been used to lead data analysis and statistics.

The predictors most influencing the MV – ordered by most significant influence – are the following (Figure 7): surface, elevator, and finishes. The MV is low compared to the localisation into the historic downtown and the ability to extract buildings by the platform. The properties under observation produce an income surplus, defined as "interstitial rent", around to 707%.

It can be noticed that the un-taxed turnover has been generating a "real bubble", in which both the taxes and the hosts turnover revolve around. The gap highlights the potential of a phenomenon that should not be blocked, but disciplined, to allow everyone to have access to the produced wealth (Figure 8).

The platform capitalism as a digital and continually evolving phenomenon has to be considered before figuring out any regulatory intervention. Therefore, the shortcoming of the traditional planning tools has been experimenting especially in terms of ineffectiveness to short-time response capacity.

Figure 8. The interstitial rent: comparison among the host turnover, the taxable income of real-estate assets and municipality income.



As a digital phenomenon, the difficulty of controlling and tracking the hosting activity is evident; therefore, it is necessary to enable procedures such as those activated in other countries of the world and Italian regions, i.d. the Lombardia, where the hosts have to be equipped with an identification code. A body of rules and strategies defending the right to the city has to be generated to re-establish natural balance and social redistribution of benefits deriving from tourism. Therefore, policies which can protect human and assets for the historic downtown have to be envisaged.

5. Discussion and conclusions

The goal focuses on integrating tourist activities within the urban rhythms and demands without conflicting with the needs of the residents by promoting collaborative and circular economy. A site-specific policy setting limitations towards the Airbnb platform and enabling circular and collaborative economy mechanism is needed. The goal is to pursue a model that is able to make not only the traditional economy more efficient and productive, but also to stimulate cooperation, collaboration, and synergies (Fusco Girard and Nocca, 2017), overcoming the traditional paradigm of tourism as an extractive industry, the aim is to calm the negative externalities deriving from tourism and to open new paths of wealth, protecting the cultural heritage, the core business of tourism, and building an alternative growth model.

The contribution is positioned in a relatively young field of research linking CE with sustainable tourism practices, showing a proposal to make operative some instances which synthetically are addressed to: (*i*) monitor the host activities accurately, (*ii*) reduce environmental risks; (*iii*) enhance the communication of rules and promote correct behaviours; (*iv*) transform the "externality adders" (Andersen, 2007) into taxes and charges.

Indeed, the proposal of a policy strategy provides for the adoption of programmatic measures for the management of tourist flows and tourist residences in the Metropolitan City of Naples. The proposed rules consider the following points.

The requirement for hosts of non-hotel tourist facilities - i.e. B&Bs, holiday homes and short-term rentals - to have a municipal identification code (CIC), when they communicate the start of the activity. The CIC can only be obtained by the structures legit, which are also subject to inspection by the local police. The CIC, indeed, certifies that the administrative process for the regulation of holiday homes and apartments has been completed. In this manner, it can be guaranteed that the host has communicated the start of the activity to the municipality and has fulfilled all the due obligations. These obligations involve:

a.1. Each structure must be approved to the firefighting directives and equipped with an extinguisher, emergency call, carbon monoxide and smoke detector, emergency kit;

a.2. The apartments must meet energy efficiency and living comfort requirements;

a.3. The respect of 90 days of downtime within the calendar year - it is not possible to have guests for 90 days, even if they are discontinuous;

a.4. Up to 49% of the total surface of the apartment, which constitutes the own main residence, can be rented at any time and without stopping the activity;

a.5. By the 15th of each month the visitor's tax must be paid for the guests and thus also report any days of "downtime";

a.6. Making receipts to guests;

a.7. Exhibiting the house rules and equipment (both in Italian and English languages);

a.8. Displaying the prices;

a.9. Communicating the tourist flows by the 5th of each month for data collection by ISTAT.

The municipality provides the hosts that have CIC with rewards on taxation to be achieved with municipal tax reliefs up to 10%. It promotes the formation of a "Community of hosts" as active actors for the determination of tourism management and control measures, together with those of physical space improving through small actions of transformation recognising the primary interest of protecting the physical and social space in which hosts' activities thrive. In this meaning, for the Municipality of Naples it is necessary to found a specific public office which links the initiatives promoted by the Community of hosts, fostering and checking the production of quality interventions.

The Community of hosts can operate implementing two types of measures: 1. immaterial measures: unified tourist card; 2. material measures: the urban design of physical spaces, through a process of setting up the urban area, often spontaneous. Therefore, the formation of a hybrid company - made up of hosts, citizens and institutional bodies - have to be promoted. Within this type of company, the capital captured by hosts through the short lease, will be partly re-invested, producing further advantages over time for tourist accommodation activities and micro-transformations which improve space of relationships and built environment. The main question, indeed, is: What are the benefits of the public entity? The different benefits can include:

b.1. The municipality allows the use of tourist tax for the implementation of the intervention measures provided by the policy;

b.2 The Municipality rewards the members of the Community of hosts through a further tax relief (up to 10%) for the time of intervention implementation;

b.3. The specific public office is able to support the Community of hosts in all the steps of interventions achievement;

b.4. Facilitations for bank loans are provided;

b.5. Tariff concessions are applied for specialist consultancy and soil occupation tax for scaffolding.

Firstly, the obligation for hosts to provide themselves with a municipal identification code would guarantee the census of non-hotel facilities by gathering these types of data for the government. Moreover, the fire certificate allows to carry out a procedure for the release of the house plan, with its cadastral con-

Table 1. Hybridisation markers (revised by Venturi and Zandonai, 2014).

Hybridisation markers	Detected elements	Further potentials
Innovation	New service models for new needs / risks	Replicability and expansion of service prototypes and business models
Governance	Balanced composition of the models: enhancement of the cooperative form, introduction of profit company models and the principle of holacracy	Dissemination of new “social” standards of the company
Partnership	Network structure of the company that brings together private individuals, citizens and bodies and institutions to create services	Implementation of models and structures of networks on a larger scale
Marketplace	“Hybrid” market transactions with the public, private and tourists	
Beneficiary	Citizens, tourists and operators in the cultural and entertainment sectors	
Finance	Polarisation of investments to support the start-up phase	Methods of interaction between the Host Community and specialised lenders
Skills	Technical skills taken from cooperation with specific university addresses	

sistency. It could enable the municipality to gather updated information on the built heritage. Civil society organisations have been recognised for their ability to actively cooperate in the process of planning interventions and adopting the necessary strategic choices, as a win-win game. On the one hand, the city will be redeveloped through punctual urban design interventions without affecting the hard structure of the city, but fostering the process of rearrangement of the urban space that has been already spontaneously arising. On the other hand, the hosts will benefit from the small renovation, improving the performance of services, which benefits both the neighbourhood community as well as the owners and the local government. In this context, the establishment of the hybrid, networked, value-generating company has to be pursued, not only by activating paths of wealth but also opening the way to positive social values extended to all Community of hosts (Table 1).

The characteristics of the prefigured hybrid enterprise are summarised below.

The composition. A business network, by which the hosts have to be involved with citizens and institutional bodies too, can be conceived as an ecosystem of resources rather than a typology of management.

The mission. The mission aims to guarantee the city safeguard by investing part of the financial resources by hosting activity in urban acupuncture interventions through cooperation and co-design ventures along with citizens. Moreover, the co-production with the municipality, university, cultural and commercial activities, has to be strengthened to boost strategies for addressing tourist flows, aiming at the sustainability of tourism together with the protection of the right to the city.

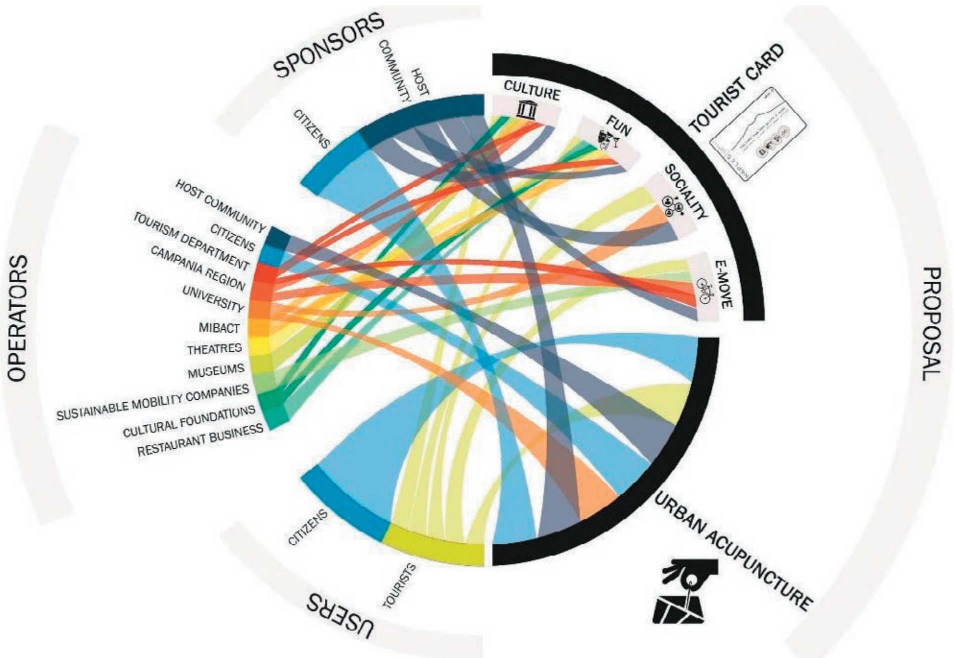
The vision. Within any phase of the company's development, the importance of safeguarding the urban landscape – understood as the inseparable set of inhabitants, environment, culture and local traditions – is primary. People and places they live have to be placed in the foreground since a person can self-determine only if the preservation of the relationships with its context has been guaranteed.

The governance. Co-governance system, conceived as holacracy, has to be pursued. The holacracy consists of a type of governance that aims to be as democratic as possible, proposing a coordinator who has been recognised by the network as the most skilful person.

The promoters of change have to be the host communities and citizens. The proposed actions concern the creation of a tourist card and urban acupuncture interventions to be carried out both through the use of specialised partners.

A tourist card has been proposed, as a tool already experimented in other cities, pursuing objectives of sustainability of tourist flows through the structuring of places that offer attractions and events that suggest less travelled destinations. Moreover, through a cyclical renewal of the offer can be avoided the overcrowded and unliveable flows for which the proposal is seeking a cure. A pragmatic approach to afford the phenomenon is crucial; trying to lay the foundations for culturally oriented tourism more sustainable for the city and its inhabitants. In a

Figure 9. The policy strategy articulation.



highly fragmented tourist offer scenario, Naples Tourist Card – proposed by the Community Host – aims at bringing together the positive skills of the current cards and enhancing the promotion of slow and curious tourism, which looks at the local specificities without being invasive. The card has a buffer that goes beyond the municipal area, extending the search for places to explore throughout the region. The research finds places that are attractive but not yet known to the general public or threatened by degradation due to abandonment. It aims at distributing tourist flows by networking between the different places of culture. In this perspective, promoting destinations means also building a common thread between them and potential tourists, managing tours and cards by smartphone through a dedicated app. The point of interest proposed by the card has been geo-located on an interactive map. By clicking on the pin through the "culture" function (A) it is possible to explore the selected place through a card that returns photos, useful information and the availability to book the chosen visit or activity (Figure 10).

Through the "fun" function (B), a series of artistic and excursion activities have been proposed to suggest events and destinations even during the evening hours, to reduce and prevent the disturbance of peace at night.

According to circular sustainable tourism, equally sustainable mobility is needed. The app, indeed, promotes alternative mobility to urban public transport, offering free use of bike-sharing and accessing bus sharing. Through the "e-move" function (C), an interactive map for the location of cycle stations for bike-sharing and bus sharing stop displays. Through the "chat" function (D), cardholders are allowed to socialise, favouring the formation of groups for travel with bus sharing. As far as the material intervention measures, the prefigured urban regeneration is featured by active and co-participatory promotion with a bottom-up and top-down approach.

The proposed micro-interventions have been divided into two macro-typologies, according to their scope: fostering the space of relationships; enhancing the

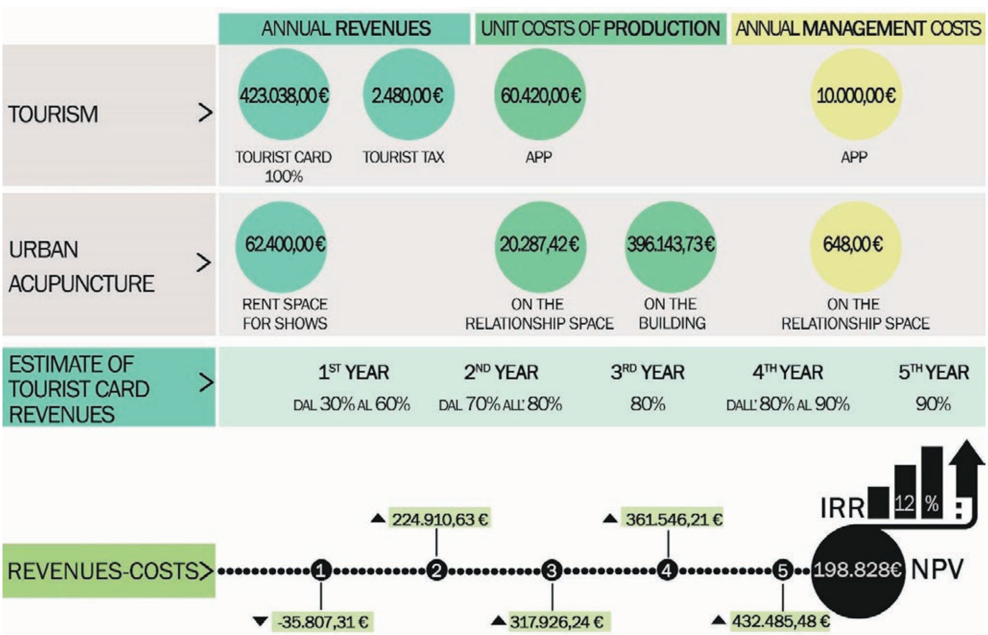
Figure 10. The Naples Tourist Card.

built heritage. The two different types of intervention find specific objectives and application criteria concerning the case considered. Referring to responses to the space of relationships, they aim to re-design the open spaces of the city, replacing the current function of parking with other facilities. The goal can be achieved through equipped spaces that encourage socialising, promoting interaction between people and offering a quiet, but not isolated, a place where you can stop, relax and attend artistic events.

Responding to needs of greater public open spaces means processing easy, low cost and incremental solutions. The interventions arise from the need to re-arrange the urban balance between positive and negative functions for common spaces. Therefore, active and bottom-up cooperation for the decisive and functional design processes should be pursued, as well as the financing of the new spaces public. For example, when interventions are going to foresee close to commercial activities in the city core, new seats can encourage purchases of food and drinks, increasing the attractive value of urban spaces and supporting local business. A design model with these features could be the "parklet" (San Francisco Planning Department, 2013).

Micro-interventions on buildings are configured as complexes of operations defined by different criteria. First, the criterion of minimal intervention has to be considered to resolve the degradation framework without altering the original state of the building. A way to reach this type of intervention involves cleaning, painting, integrating small deteriorated parts, replacing elements without structur-

Figure 11. The results of the Financial Analysis.



al function. Furthermore, the interventions have to guarantee the safety of roads avoiding the danger of falling material from deteriorated elements on the facade, i.d. stone cornices, rubble, etc. At the same time, interventions to ensure their effectiveness have to be guided by respect for the relationship with the urban context and made by traditional materials, compatible integration with the existing elements, preserving the authentic image of places. Last, to ensure agreement of the interventions and their ongoing maintenance, the use of inhabitants' knowledge and skills has to be encouraged by promoting active and bottom-up cooperation.

The economic benefit of the collaborative economy can be elicited by the financial analysis to assess the proposed experience with the host community. Production and management costs/revenues have been calculated to determine the Net Present Value (NPV) and the Internal Rate of Return (IRR) (Figure 11). In our case, the NPV is greater than zero, and the IRR is 12%; therefore, we can confirm positive results for the hybrid company, whose main feature embraces the social domain. Through timetable, the phases for the implementation of the interventions have been planned. All proposals will be completed within four years.

The observed outcomes involve: the economic benefit of networking; the give back to the Community of hosts; the contribution to sustainable and circular tourism. The future steps are going to amplify benefits by providing: the expansion of bottom-up cooperation; the activation of workshops for sustainable and circular tourism awareness; the scaling up to other neighbourhoods of the city.

In conclusion, the contribution highlights that actions mitigating conflicts between tourists and citizens have to be pursued through the urban planning and resources management (Torre et al., 2015), the active involvement of citizens, and the conscious intervention by the public administration, to avoid that the historic downtown, once emptied of meaning, are going to turn themselves to "theme park" (D'Eramo, 2017). Therefore, Rodríguez et al. (2020) remarked the importance to achieve a multidisciplinary perspective involving scientists, academicians, residents, and public administration to operationalise CE principles and practices for a more sustainable tourism industry. The long-term positive externalities of tourism must be exploited, preserving the attractive capacity of the city and the presence of residents who liven up the urban scene.

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ANNEXES

Indicators table

Indicators	Item of assessment	Unit of Measure	Value
Age	Building	from 10 to 20 years ago	1
		last century (19th - 20th)	0.7
		pre-nineteenth century	0.4

Indicators	Item of assessment	Unit of Measure	Value
Typology	Building	single	1
		row house	0.7
		multifamily	0.4
Finiture	Building	historical	1
		noble	0.7
		civil	0.4
		low-cost	0.1
Conservation status of real estate unit	Building	fine refurbishment	1
		refurbishment	0.7
		no refurbishment	0.4
Surface	Building	square metres	
Floor	Building	high (up to ⅔ of height)	1
		medium (between ⅓ and ⅔ of height)	0.7
		low (⅓ of height)	0.4
Balcony	Building	yes	1
		no	0
Lift	Building	present o inutile (?)	1
		absent (between ⅓ and ⅔ of height)	0.7
		absent (up to ⅔ of height)	0.4
Panoramic view	Building	fine view	1
		ordinary view	0.7
		view on internal courtyard	0.4
Brightness	Building	yes	1
		no	0
Maintenance status	Building	excellent	1
		medium	0.7
		worst	0.4
Common space	Building	absent	1
		courtyard	0.7
		garden	0.4
Average building quality	Building	excellent	1
		medium	0.7

Indicators	Item of assessment	Unit of Measure	Value
		worst	0.4
Location	Building	central zone (main streets)	1
		medium-centered (alleys)	0.7
		fringe	0.4
Historical value of building	Building	pre-nineteenth century - fine architecture	1
		pre-nineteenth century - civil architecture	0.7
		later period	0.4
Historical value of neighborhood	Neighborhood	high	1
		medium	0.7
		null	0.4
Touristic allure	Neighborhood	high	1
		medium	0.7
		null	0.4
Parking availability	Neighborhood	assigned parking inside	1
		parking outside (on street)	0.7
		absent	0.4
Closeness to public transportation	Neighborhood	distance minor than 500 metres	1
		distance between 500 and 700 metres	0.7
		distance major than 700m	0.4
Services	Neighborhood	differentiated services	1
		prevalent services	0.7
		absence	0.4
Climate	Neighborhood	mostly mild	1
		mostly rainy	0
Closeness to green spaces	Neighborhood	distance minor than 850 metres	1
		distance between 850 and 900 metres	0.7
		distance major than 900m	0.4
Demography	Neighborhood (census tract)	number	
Foreigners	Neighborhood (census tract)	number	

Indicators	Item of assessment	Unit of Measure	Value
Residents education level	Neighborhood (census tract)	Majority of graduate residents	1
		Majority of middle school residents	0.7
		Majority of illiterate	0.4
Employers	Neighborhood (census tract)	number	
Unemployers	Neighborhood (census tract)	number	
Workforce	Neighborhood (census tract)	number	
Income earner	Neighborhood (census tract)	number	
Family with 1 member	Neighborhood (census tract)	number	
Family with 2 member	Neighborhood (census tract)	number	
Family with 3 member	Neighborhood (census tract)	number	
Family with 4 member	Neighborhood (census tract)	number	
Family with 5 member	Neighborhood (census tract)	number	
Family with more than 6 member	Neighborhood (census tract)	number	
Empty apartments	Neighborhood (census tract)	number	
No residents apartment occupied	Neighborhood (census tract)	number	
Family living in renting apartments	Neighborhood (census tract)	number	
Family living in owners apartments	Neighborhood (census tract)	number	
Family living in apartments for other reason	Neighborhood (census tract)	number	
Criminality (2017-2018)	Neighborhood	high (homicides and attempted murders)	1
		medium (robberies and intimidations)	0.7
		low (thefts and snatches)	0.4
Job opportunities	Neighborhood	differentiated sector	1
		low or seasonal (catering and sales)	0.7
		tourism sector (b&b)	0.4

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Parole chiave: *Valutazione della vulnerabilità sismica (SVA), Analisi multi-criterio (MCDC), Sistemi Informativi Territoriali (SIT)*
JEL codes: *C31, C38, O18, R58*

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Modelli Decisionali Multi Criterio per l'analisi della vulnerabilità sismica a scala territoriale: il caso studio della Garfagnana (Toscana)[1]

Italy is one of the countries with the greatest historic heritage in the world, but also one of the most seismic. In this context an earthquake can cause significant damage. Usually, the vulnerability of a building is verified with in-depth and expensive structural assessment, without considering spatial relations and local context. In this study a method is proposed for the assessment of Territorial Seismic Vulnerability, based on both building characteristics and morphological and spatial parameters. It is an urban-scale approach that allows an objective classification of buildings using an economical procedure. The method, based on the development of a geographical Multiple Criteria Decision Making model and on the participatory approach of the Analytic Hierarchy Process, has been tested in the study area of Garfagnana (Tuscany). The model can be a useful support tool for urban planning, allowing the optimization of public resources in the most vulnerable areas.

1. Introduzione

Il territorio italiano si caratterizza per frequenti e catastrofici eventi sismici. Il National Institute of Geophysical and Vulcanology identifica ogni anno in Italia da 1700 a 2500 eventi con una intensità pari o superiore a 2.5 M_L[2]. Nell'Appennino Centrale sono stati documentati terremoti di forte intensità già a partire dal XI secolo ed eventi sismici rilevanti (con magnitudo ≥ 6,0) sono stati catalogati per gli ultimi cinque secoli (AA.VV., 2014). In questo contesto, la diffusa presenza di edifici storici realizzati con materiali edili locali (es. pietra e terracotta), con elevata densità edilizia e localizzati all'apice di promontori montani o contrafforti rocciosi, sono tra i principali fattori che hanno contribuito a incrementare le perdite in termini di vite umane e patrimonio urbano (Atzori *et al.*, 2009). I centri storici rappresentano sicuramente risorse fondamentali per lo sviluppo turistico ed economico del Paese, ma anche fattori che amplificano la vulnerabilità sismica dei luoghi e quindi la propensione al danno in caso di terremoto. Un altro aspetto rilevante riguarda la distinzione tra politiche di prevenzione e di ricostruzione. Come sostiene Woo "Il bilancio globale delle vittime dei terremoti è una tragica prova della continua necessità di migliorare il sistema decisionale sugli interventi in caso di

1 The authors wish to thank the two anonymous Referees for their suggestion.
2 ML Magnitudo Locale (Scala Richter). Fonte: http://legacy.ingv.it/FAQ/faq.html#when

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terremoti" (Woo, 2011, p. 7). Per quanto riguarda la prevenzione al rischio sismico nel lungo termine risulta fondamentale l'attuazione di politiche efficienti di pianificazione territoriale. La gestione dell'emergenza invece richiede efficaci piani di soccorso e gestione delle catastrofi, accuratamente predisposti in una fase antecedente l'emergenza e ottenuti grazie alla sinergia tra i risultati della ricerca scientifica e le competenze tecniche degli operatori del settore.

Per questo, a partire dal 1909 attraverso il Regio Decreto n. 542[3], sono stati introdotti indicatori specifici per la definizione delle zone sismiche e del rischio sismico, dove per rischio sismico si intende la misura del potenziale danno economico, sociale ed ambientale derivante da un evento sismico, stimata come prodotto di tre fattori: la pericolosità, l'esposizione (o valore esposto) e la vulnerabilità, che indica la suscettibilità di un edificio a subire danni (Barbat *et al.*, 2009). Il decreto faceva riferimento ai territori colpiti dai terremoti distruttivi di Reggio Calabria e Messina del 1908. La classificazione sismica dei Comuni italiani è stata poi estesa a tutto il territorio nazionale con il D.M. n. 515 del 3 Giugno 1981[4] e il D.M. 29 febbraio 1984[5], sulla base di su uno studio di tipo probabilistico condotto dal Consiglio Nazionale delle Ricerche (CNR). Tali decreti hanno costituito la base per l'aggiornamento della classificazione sismica avvenuto con l'emanazione dell'O.P.C.M. n. 3274 del 2003[6]. Con questa ordinanza è stata resa obbligatoria la verifica di vulnerabilità sismica per i cosiddetti edifici strategici e rilevanti, cioè quelle costruzioni che risultano particolarmente funzionali alle attività di protezione civile nel corso di eventi sismici (es. punti di raccolta, vie di fuga, centri di coordinamento per le attività di protezione civile) o le cui conseguenze ad un eventuale collasso si rivelerebbero estremamente dannose per la popolazione e il contesto territoriale[7]. Si tratta di una verifica estremamente costosa, diventata quindi obbligatoria per scuole, municipi, ospedali ecc., ma non per edifici residenziali, industriali o produttivi[8]. A tale norma ha fatto seguito il D.M. 28 febbraio 2017 n. 58[9] che individua due metodi per la determinazione della classe di rischio sismico, uno di carattere convenzionale e uno di carattere semplificato, per contenere i costi della valutazione della vulnerabilità sismica dei singoli edifici. Si tratta però

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[3] Regio Decreto n. 542 del 15 Luglio 1909 "Estensione a tutti i Comuni della Calabria e dei Circondari di Messina e Castroreale le norme tecniche ed igieniche approvata dal R.D. 18 aprile 1909, n. 193, e fissa le aree per le nuove edificazioni." (G.U. n. 185 del 9 Agosto 1909).

[4] D.M. n. 515 del 3 Giugno 1981. Riguardante la classificazione sismica del territorio e basati su uno studio del CNR.

[5] D.M. del 29 Febbraio 1984 Riguardante la classificazione sismica del territorio e basati su uno studio del CNR.

[6] O.P.C.M. del 20 marzo 2003, n. 3274, "Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica". (GU Serie Generale n.105 del 08-05-2003 - Suppl. Ordinario n. 72).

[7] art. 2, comma 3, O.P.C.M. 3274/2003.

[8] Ibidem.

[9] D.M. 28 febbraio 2017 n. 58 "Sisma Bonus - Linee guida per la classificazione del rischio sismico delle costruzioni nonché le modalità per l'attestazione, da parte di professionisti abilitati, dell'efficacia degli interventi effettuati." poi modificato dal D.M 7 marzo 2017 n. 65.

di una stima soggettiva legata alle competenze dei molteplici tecnici che possono eseguire le analisi sui singoli edifici delle aree urbanizzate.

L'analisi di vulnerabilità sismica a livello territoriale rappresenta invece una valutazione di contesto, che non esamina solo le caratteristiche morfologico-strutturali del singolo edificio, ma anche: le relazioni spaziali tra i vari edifici; le relazioni con le vie di fuga e gli spazi aperti; le caratteristiche geomorfologiche dei terreni su cui insistono gli edifici. Questo tipo di analisi è stata affrontata in numerosi studi (Alizadeh *et al.*, 2018; Walker *et al.*, 2014), ma solo pochi hanno integrato gli aspetti connessi alla morfologia territoriale (Armaş, 2012; Jenness, 2006; Karimzadeh e Matsuoka, 2018). La criticità evidenziata da tali studi è rappresentata dalla difficoltà di acquisizione di archivi dati completi ed esaustivi (inventario degli edifici, informazioni sulla rete viaria, ecc). Per questo, una valida soluzione è legata all'impiego di metodologie in grado di utilizzare dati telerilevati, ovvero metodologie GIS capaci di acquisire dati in modo speditivo grazie all'uso di immagini satellitari o foto aeree (Alizadeh *et al.*, 2018; Bono e Gutiérrez, 2011; Erden e Karaman, 2012; Rezaie e Panahi, 2015). La valutazione della vulnerabilità sismica territoriale basata su sistemi di informazione geospaziali può quindi rappresentare la soluzione al problema della limitata disponibilità di dati (Hizbaron *et al.*, 2012; Kougkoulos *et al.*, 2018; Servi, 2004; Sinha *et al.*, 2016).

Nel presente lavoro viene proposta la valutazione della Vulnerabilità Sismica Territoriale (VST), misurata in relazione alle specifiche caratteristiche strutturali e all'organizzazione spaziale e funzionale del sistema urbano in cui gli edifici sono inclusi. Si tratta di un approccio a scala urbana che consente una classificazione omogenea dell'edificato senza risentire della diversa sensibilità e professionalità dei tecnici coinvolti, garantendo costi estremamente contenuti rispetto a quelli necessari nel caso di approfondite classificazioni di vulnerabilità sui singoli edifici. La metodologia si basa sullo sviluppo di un modello di analisi multicriteriale geografico (MCDM GIS) fondato sull'approccio partecipativo garantito da un processo di analisi gerarchica (AHP) (Erden e Karaman, 2012; Malczewski, 1999; Saaty, 1977, 1980; Silavi *et al.*, 2006). I database per la costruzione degli indicatori derivano sia da dati telerilevati, sia da archivi facilmente reperibili presso le Pubbliche Amministrazioni (PP.AA.) (es. carta tecnica regionale). La metodologia è stata testata in un territorio caratterizzato da una pericolosità sismica di classe 2[10] su cui sussistono buone probabilità di forti terremoti, cioè l'area della Garfagnana situata nella parte settentrionale della Regione Toscana. L'area si trova vicino a un importante sistema di faglie dell'Appennino centrale: l'Etrurian Fault System[11].

2. Stato dell'arte

In letteratura esistono diverse definizioni di vulnerabilità sismica dell'edificato (Alizadeh *et al.*, 2018; Karimzadeh *et al.*, 2014; Lagomarsino e Podestà, 2004) e ad

[10] OPCM 3274 del 20/03/2003.
[11] https://ingvterremoti.com/2013/02/06/

esse sono legate differenti metodologie di valutazione. Una prima classificazione proposta da Vicente *et al.* (2011) mette in relazione i metodi alle tecniche di analisi impiegate, distinguendo tra:

- tecniche dirette: basate su indicatori sintetici che riassumono il livello di vulnerabilità degli edifici. (Calvi, 1999; D'Ayala e Speranza, 1999);
- tecniche indirette: basate su un set di indicatori in grado di stimare il danno atteso (es. metodo ATC-21, 1988; schede GNDT, 1994);
- tecniche convenzionali: fondate su un indice di vulnerabilità al quale non viene poi associata una previsione di danno (es. metodo ATC-13, 1985; metodo HAZUS, 1999).
- Un'altra classificazione proposta da Novelli nel 2017 si fonda sulle modalità di esecuzione dell'analisi e sulle basi conoscitive e le fonti dati utilizzate. In questo caso sono differenziati:
- metodi empirici: basati su elaborazioni di dati derivati dall'osservazione di danni subiti dagli edifici a causa di eventi sismici passati (Barbat *et al.*, 2009; Vicente *et al.*, 2011);
- metodi analitici: basati su modelli numerici che stimano la risposta sismica dell'edificio (Karimzadeh e Matsuoka, 2018; Lourenço e Roque, 2006);
- metodi soggettivi: basati sul giudizio di esperti (Zuccaro *et al.*, 2015);
- metodi ibridi: basati su diverse fonti di dati (Novelli, 2017).

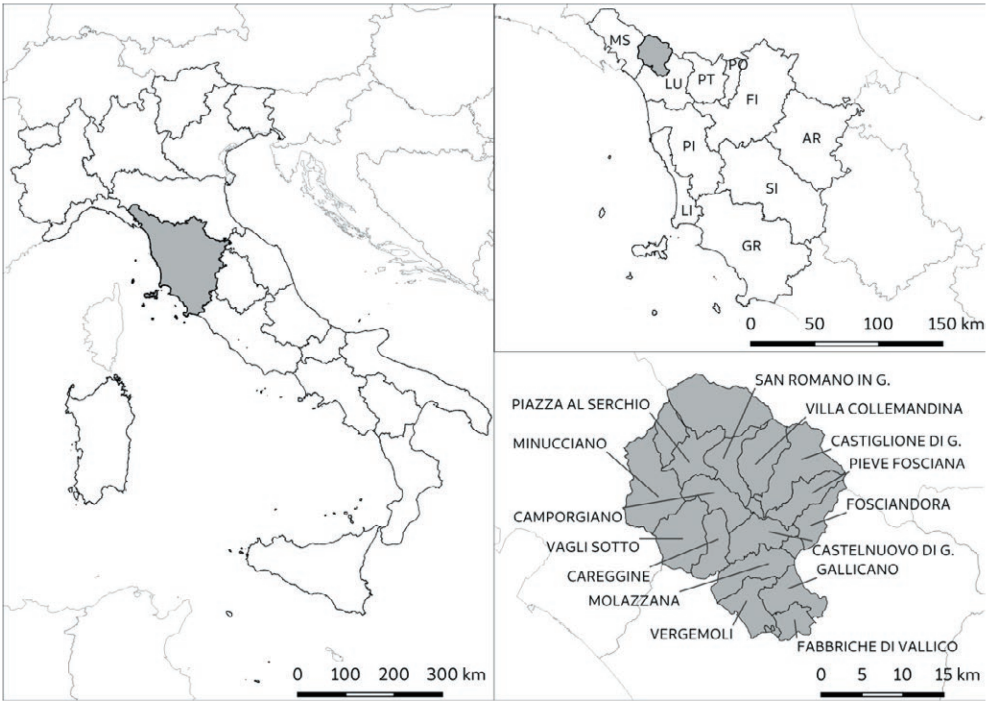
La metodologia proposta applica una tecnica convenzionale (poiché definisce un Indice di Vulnerabilità Sismica Territoriale), con l'uso di dati empirici (es. indagini storiche su tecniche e materiali di costruzione) e metodi analitici (es. Topographic Position Index). Inoltre, la metodologia in oggetto propone il passaggio da un modello di analisi della vulnerabilità sismica a scala di singolo edificio (Lourenço e Roque, 2006) ad uno a scala territoriale (Alizadeh *et al.*, 2018; Armaș 2012), per il quale è necessario evolversi da un approccio di tipo ingegneristico-strutturale ad un'analisi di tipo geo-spaziale. Molti modelli di analisi territoriale proposti in letteratura studiano gli aggregati urbani (Vicente *et al.*, 2011) e la morfologia del territorio (Costanzo *et al.*, 2016; Hizbaron *et al.*, 2012), ma restano ancora strettamente connessi all'indagine di carattere strutturale-architettonico del singolo edificio (Karimzadeh *et al.*, 2014; Lourenço e Roque, 2006) o considerano altri parametri come la pericolosità sismica e l'esposizione (Armaș 2012). Nel caso di studio la metodologia si riconduce ad approcci già sviluppati da altri autori (Alizadeh *et al.*, 2018; Karimzadeh *et al.*, 2014; Silavi *et al.*, 2006), ma approfondisce aspetti legati ad indicatori macrostrutturali dell'edificato (es. altezza degli edifici), della struttura urbana (es. densità edilizia) e della morfologia del territorio sul quale insistono gli edifici (es. Topographic Position Index).

3. Caso studio: la Garfagnana

L'area di studio (Figura 1) si sviluppa su 15 Comuni situati nella parte Nord-Ovest della Toscana in Provincia di Lucca (la c.d. Garfagnana).

La struttura insediativa di questo territorio è caratterizzata da numerosi nuclei urbani di dimensioni ridotte e prevalente origine rurale. Lo sviluppo dei cen-

Figura 1. Inquadramento dell'area di studio: la Garfagnana (fonte: nostra elaborazione).



tri abitati di fondovalle invece è relativamente recente. Questa conformazione del territorio urbanizzato deriva dalla struttura orografica e idrografica locale, caratterizzata dalla presenza di due catene montuose (Appennini e Alpi Apuane) e del bacino del fiume Serchio. L'area, localizzata in corrispondenza di un importante sistema di faglie dell'Appennino centrale (Etrurian Fault System), si caratterizza per una classe di pericolosità sismica di livello 2 e rientra quindi nella fascia territoriale a maggiore pericolosità sismica della Regione Toscana.

4. Materiali e metodi

Come anticipato, l'analisi della vulnerabilità sismica territoriale è concepita come un problema spaziale e non come una valutazione dei parametri caratterizzanti il singolo manufatto edilizio (Rashed e Weeks, 2003). Per questo la metodologia integra da un lato sistemi informativi geografici per la geolocalizzazione dei dati e dall'altro un processo decisionale basato su modelli multicriteriali (MCDM) spaziali, caratterizzati da parametri rappresentati attraverso layers cartografici (Alizadeh *et al.*, 2018; Armaş, 2012; Rezaie e Panahi, 2015; Sinha *et al.*, 2016). La revisione bibliografica dei modelli MCDM spaziali, sviluppati per l'analisi della vulnerabilità sismica, evidenzia che il metodo più comunemente applicato è basato sul processo di analisi delle gerarchie (AHP) (Alizadeh *et al.*, 2018; Barbat *et al.*, 2009; Rezaie e Panahi, 2015; Sadrykia *et al.*, 2017), sviluppato da Saaty nel 1977. Il metodo da un lato permette di ponderare la rilevanza dei vari indicatori sulla base di giudizi di esperti e dall'altro di quantificare criteri in aree con carenza di dati (Sadrykia *et al.*, 2017). La possibilità di avere un quadro conoscitivo georeferenziato, con indicatori morfologici e urbanistici ad elevata risoluzione spaziale (10x10m), rappresenta un valido supporto per il decisore pubblico che deve definire interventi mirati alla salvaguardia dell'incolumità delle popolazioni in un'ottica di razionalizzazione delle risorse disponibili (Alizadeh *et al.*, 2018; Bernetti e Fagarazzi, 2002; Cozzi *et al.*, 2016).

4.1 MCDM

I modelli di analisi multicriteriale spaziale si caratterizzano per il fatto che i risultati dipendono dalla localizzazione geografica, dalla forma e dalla dimensione degli oggetti ricavati dai dati di input. Tali modelli vengono prevalentemente rappresentati attraverso geodatabases di tipo raster. (Bernetti, 2006; Bernetti e Fagarazzi, 2002; Eastman e Jiang, 1995; Jiang e Eastman, 2000; Mogorovich, 2019). Per questo nei modelli MCDM spaziali ciascun criterio decisionale, ovvero ciascun fattore che incrementa o decrementa la vulnerabilità di un territorio per un dato aspetto (morfologia, densità edilizia, altezza edifici, ecc.), è rappresentato tramite uno specifico layer raster, in cui le variabili decisionali del modello sono rappresentate dai valori che assumono i diversi pixels e che esprimono la vocazionalità del territorio verso un dato aspetto (es. vulnerabilità sismica). Formalmente definito P_j il pixel *j*-esimo in una rappresentazione raster di un dato territorio e $x_{i,j}$ il valore assunto dal *j*-esimo pixel per l'*i*-esimo criterio, l'insieme dei criteri decisionali del problema può essere definito come:

$$P_j = \{x_{i,j} | x_{i,j} \in [0,1], \quad i = 1,2,\dots,m; j = 1,2,\dots,n\} \tag{1}$$

4.1.1 La normalizzazione e aggregazione dei dati

I criteri decisionali, rappresentati dai layers tematici sono generalmente espressi con indicatori che presentano diverse unità di misura. Basti pensare alle grandezze con cui sono espresse la pendenza (%) e l'altezza degli edifici (m). Per questo è quindi necessaria una loro normalizzazione nell'intervallo [0,1] prima di procedere all'aggregazione dei criteri secondo i procedimenti previsti nei modelli MCDM. Il metodo più semplice per effettuare tale normalizzazione è quello della distanza dal punto ideale o del valore massimo riscontrato per ogni criterio (Malczewski, 1999):

$$x_{i,j} = \frac{R_{i,j} - R_i^{min}}{R_i^{max} - R_i^{min}} \qquad R_i^{min} = 0 \rightarrow \quad x_{i,j} = \frac{R_{i,j}}{R_i^{max}} \tag{2}$$

Con:
$x_{i,j}$= valore normalizzato [0,1] del criterio *i*-esimo per il pixel *j*-esimo;
$R_{i,j}$= valore non normalizzato del criterio *i*-esimo per il pixel *j*-esimo;
R_i^{min}= valore minimo del criterio *i*-esimo nel territorio esaminato;
R_i^{max}= valore massimo del criterio *i*-esimo nel territorio esaminato.

Nel presente studio il processo di normalizzazione si è basato sul criterio della distanza dall'ideale (Bernetti e Fagarazzi, 2002; Romano, 2006).

Considerato che lo scopo dei modelli MCDM spaziali è generalmente rappresentato dalla definizione di un indice complessivo che rappresenti i diversi criteri esaminati si è quindi proceduto all'aggregazione di tali criteri secondo la regola basata sulla loro somma pesata. In tale procedimento i pesi w_i attribuiti ai singoli criteri *i*, sono funzione dell'importanza relativa data dai decisori e tale che $\sum w_i=1$. Formalmente tale regola di aggregazione può essere rappresentata:

$$V_j = \sum_{i=1}^{n} x_{i,j} w_i \quad (3)$$

Dove:
V_j = vulnerabilità sismica del pixel *j*-esimo;
$x_{i,j}$= valore normalizzato [0,1] del criterio *i*-esimo per il pixel *j*-esimo;
w_i = peso del criterio *i*-esimo;
n = numero di criteri *i*-esimi.

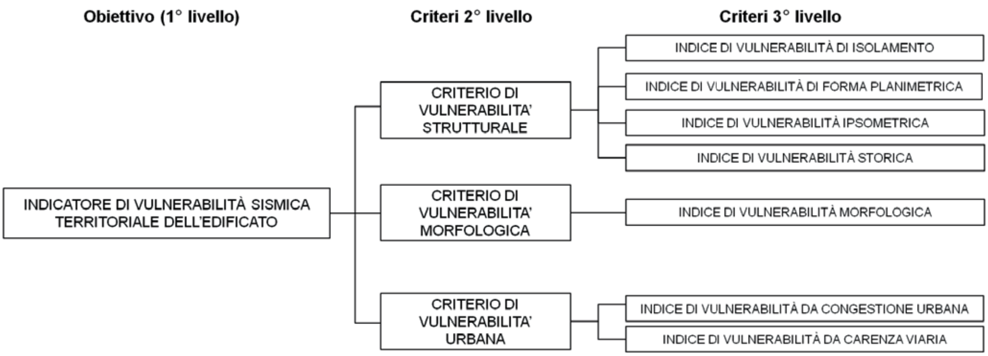
4.1.2 Definizione del vettore pesi con metodo AHP

Una delle tecniche maggiormente utilizzate per la definizione dei pesi relativi w_i di ciascun criterio *i* fa riferimento alla teoria dell'analisi gerarchica AHP sviluppata da Saaty nel 1977 (Alizadeh *et al.*, 2018; Dodgson *et al.*, 2009; Malczewski, 2004; Saaty, 1980). In particolare l'AHP si caratterizza per la possibilità di essere in grado di valutare problemi decisionali anche complessi e di permettere l'applicazione di modelli in ambito mono o multi decisionale (Bernetti, 2006). Il metodo, applicato in molteplici analisi della vulnerabilità sismica dei territori (Alizadeh *et al.*, 2018; Barbat *et al.*, 2009; Rezaie e Panahi, 2015; Sadrykia *et al.*, 2017) si basa su una serie di steps.

Durante la prima fase di scomposizione del problema decisionale, gli elementi caratterizzanti sono stati disaggregati nel diagramma gerarchico sulla base di criteri e sottocriteri[12] che identificano aspetti omogenei del problema (in questo caso: infrastrutture, morfologia del territorio, ecc.) (Alizadeh *et al.*, 2018; Dodgson *et al.*, 2009; Malczewski, 2004; Saaty, 1980). Sono stati quindi definiti: l'obiettivo generale di primo livello, i criteri di secondo e terzo livello (Figura 2).

[12] Si ricorda che i criteri di uno stesso livello sono mutuamente indipendenti (Saaty 1980).

Figura 2. Procedimento di gerarchizzazione AHP (fonte: nostra elaborazione).



Nella seconda fase, sono state costruite tre matrici di confronto a coppie, che hanno permesso la comparazione di tutti i criteri di secondo livello e dei sottocriteri di terzo livello relativi ai criteri di vulnerabilità strutturale e di vulnerabilità urbana. Le matrici sono state sottoposte a un panel di decisori che hanno espresso le loro priorità comparando a coppie i criteri. Al fine di ottenere un'analisi completa dei parametri sottoposti a giudizio, è stato costituito un gruppo di 12 esperti provenienti da diverse discipline. Tra questi: due architetti, due geometri, due geologi, tre ingegneri e tre urbanisti. I soggetti coinvolti nello studio provengono in parte dell'ambiente accademico e in parte da studi privati di settore. La valutazione si è basata su una successione di domande quali-quantitative, ovvero: quale dei due fattori è maggiormente rilevante? Quanto è più rilevante? Per rispondere alla seconda domanda è stato fatto riferimento alla scala di importanza relativa utilizzata dallo stesso Saaty (1980), che permette di esprimere un giudizio positivo con un valore compreso tra (1) e (9) (Fagarazzi, 2006).

Nella terza fase è stato stimato il peso dei singoli criteri tramite il metodo degli autovalori, mentre nella quarta ed ultima fase è stata effettuata l'analisi di consistenza dei giudizi attraverso l'Indice di Consistenza (CI) della matrice (Saaty, 1980), per verificare la coerenza tra i giudizi espressi dai singoli decisori. Saaty, nel 1980, ha sviluppato uno specifico indice in grado di esprimere il livello di consistenza delle matrici di confronto a coppie. L'indice è definito dalla seguente equazione:

$$CI = \frac{\alpha_{max} - n}{n-1} \qquad (4)$$

Dove:
α_{max} = autovettore max della matrice;
n = ordine della matrice.

Lo stesso Saaty ha fornito una regola pratica per la valutazione della bontà degli giudizi. Se il CI assume valori minori o uguali a 0.1, allora il valutatore si può ritenere soddisfatto dei suoi giudizi (D'Apuzzo e Ventre, 1995). Il CI di ogni tabella di confronto a coppie sottoposta ai diversi esperti è risultato essere inferiore a 0.1, esprimendo quindi una consistenza accettabile nella coerenza dei giudizi espressi (Tabella 4, Tabella. 6).

Il coinvolgimento dei decisori nell'ambito dell'analisi AHP è stato effettuato in modo individuale per evitare problematiche come la polisemia dei termini, causata dal fatto che il codice linguistico non è pienamente condiviso nel gruppo, la comunicazione non è perfetta (Marradi, 1994) e si può incorrere nel condizionamento dovuto alla presenza di soggetti carismatici che non consentono la libera espressione delle posizioni minoritarie (Tourangeau e Rasinski, 1988). Il coinvolgimento individuale ha quindi richiesto la definizione di una metodologia di aggregazione dei vettori pesi individuati dai singoli decisori. Operativamente, i metodi di aggregazione delle preferenze più frequentemente utilizzati sono tre (Haimes e Chankong, 1985; Kacprzyk *et al.*, 1988): la valutazione additiva, la valutazione moltiplicativa e la logica sfocata (Romano, 2006). In questo caso è stato scelto un metodo di aggregazione delle preferenze di tipo moltiplicativo in modo da enfatizzare l'impatto della valutazione di ciascun decisore sul risultato dell'aggregazione. In particolare, come anche proposto da Aczél e Saaty nel 1983 per lo sviluppo del metodo AHP, è stata utilizzata la media geometrica come metodo di aggregazione (Bernetti, 2006). Per cui, dati *S* decisori (dove *S* =, con s = 1, ..., *n* decisori), il peso globale o complessivo di ogni criterio *i-esimo* sarà pari a:

$$W_i = \sqrt[n]{\prod_{s=1}^{n} w_{s,i}} \quad (5)$$

Dove:
W_i = peso complessivo del criterio *i*-esimo
$w_{s,i}$ = peso attribuito dal decisore *s*-esimo
n = numero complessivo dei decisori

In tal modo, è stato introdotto un approccio valutativo dei decisori totalmente non compensatorio, fino al caso limite della situazione di veto allorché un decisore attribuisce ad un criterio una valutazione pari a zero (Romano, 2006).

4.2 Le basi dati

Il Sistema Informativo Territoriale (o SIT) ha rappresentato l'elemento nodale per lo sviluppo del modello MCDM spaziale. L'archivio è stato realizzato sia in formato vettoriale che in formato raster, con celle quadrate di 10x10m, in modo da sviluppare un'analisi ad un dettaglio tale da poter discriminare il singolo edifico o la singola strada. L'impiego di basi dati raster rappresenta la configurazione più diffusa nell'ambito degli studi sulla vulnerabilità sismica in ragione delle sue elevate potenzialità e capacità elaborative(Alizadeh *et al.*, 2018; Barbat *et al.*, 2009; Rezaie e Panahi, 2015; Sadrykia *et al.*, 2017).

Le basi dati utilizzate traggono origine dal portale GEOscopio della Regione Toscana[13] e si caratterizzano per i seguenti layers cartografici:

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[13] https://www.regione.toscana.it/-/geoscopio

- Archivio degli edifici (vettoriale): sedimi edilizi toscani periodizzati con sei soglie temporali dal 1832 al 1996[14] contenenti informazioni su: quota piano di campagna, quota piano di gronda; numero piani fuori terra; altezza degli edifici; periodizzazione storica; tipologia d'uso dell'edificio; area; volume; perimetro.
- Archivio degli edifici pubblici strategici e rilevanti (vettoriale): relativo agli edifici strategici individuati in Toscana dal Dipartimento di Protezione Civile con disponibilità di informazioni su materiale di costruzione e analisi di vulnerabilità effettuate[15].
- Carta Tecnica Regionale in scala 1:10˙000 (vettoriale e raster): da cui sono derivati gli archivi cartografici del grafo stradale (distinti per tipologia, larghezza, ecc.).
- Digital Terrain Model (DTM): raster appositamente costruito (10x10m) sulla base delle primitive quotate (punti e linee) della Carta Tecnica Regionale in scala 1:10˙000.

4.3 Indice di Vulnerabilità Sismica Territoriale

4.3.1 Criterio di vulnerabilità strutturale

In letteratura, molti studi hanno esaminato la correlazione esistente tra i parametri strutturali in ambito sismico, tra i quali: la regolarità planimetrica, l'altezza e l'epoca di costruzione, la stabilità strutturale degli edifici (Alizadeh *et al.*, 2018; Banica *et al.*, 2017; Guéguen *et al.*, 2007; Sarris *et al.*, 2010; Zuccaro *et al.*, 2008).

Il criterio di vulnerabilità strutturale è stato definito dalla combinazione di quattro sub-criteri:

- Indice di vulnerabilità di isolamento (Ii);
- Indice di vulnerabilità di forma planimetrica (Fp);
- Indice di vulnerabilità ipsometrica (Ih);
- Indice di vulnerabilità storica (Ivs).

L'aggregazione dei quattro sub-criteri è stata realizzata grazie ad un'operazione di mapalgebra, che ha consentito la somma pesata delle quattro mappe raster dei singoli sub-criteri.

Indice di vulnerabilità di isolamento

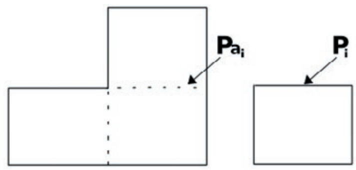
L'indice valuta le interazioni statiche tra edifici contigui. Rappresenta un parametro molto importante nella valutazione degli aggregati urbani localizzati in contesti sismici (Armaş, 2012; Vicente *et al.*, 2011). Formalmente misura il grado di inclusione strutturale di un edificio rispetto a quelli adiacenti. L'indice di vulnerabilità di isolamento assume valori pari a 0 quando è totalmente isolato e quindi strutturalmente meno vulnerabile a eventi sismici per effetto di edifici contigui, mentre assume valori pari a 1 quando è totalmente incluso in altri edifici (Figura 3). È calcolato per singolo edificio ed è dato da:

[14] Catasto Generale Toscano. Fonte: http://www.archiviodistato.firenze.it/catastotoscano/
[15] https://www.regione.toscana.it/-/patrimonio-edilizio-pubblico-in-toscana

$$I_a = \frac{Pa_i}{P_i} \tag{6}$$

Dove:
P_{ai} = porzione del perimetro dell'edificio *i*-esimo coincidente con il perimetro di altri edifici adiacenti;
P_i = perimetro dell'edificio *i*-esimo.

Figura 3. Perimetri aggregati (fonte: nostra elaborazione).



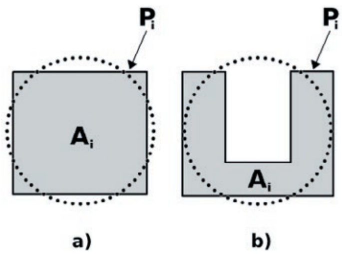
Indice di vulnerabilità di forma planimetrica

L'indice valuta la vulnerabilità sismica conseguente alla forma planimetrica degli edifici. In particolare, considerato che una planimetria compatta conferisce maggiore stabilità sismica agli edifici (Guéguen *et al*., 2007; Vicente *et al*., 2011; Zuccaro *et al*., 2008), si assume che la forma circolare sia quella in grado di garantire la maggiore stabilità strutturale ed un buon comportamento antisismico (Paolillo, 2005). L'indice di vulnerabilità di forma planimetrica tende quindi a 1 quanto più la planimetria del singolo edifico è articolata e dispersa (Figura 4b), mentre tende a 0 quanto più la planimetria dell'edificio è compatta e approssimabile a quella di un cerchio (Figura 4a). L'indice, calcolato per singolo edificio, è dato da:

$$C_f = 1 - \frac{2\pi \sqrt[2]{A_i/\pi}}{P_i} \tag{7}$$

Dove:
A_i = superficie dell'edificio *i*-esimo;
P_i = perimetro dell'edificio *i*-esimo.

Figura 4. Relazione stabilità/forma planimetrica (fonte: nostra elaborazione).



Indice di vulnerabilità ipsometrica

L'indice valuta la vulnerabilità sismica conseguente all'altezza degli edifici, parametro che rende le costruzioni particolarmente vulnerabili ad eventi sismici (Alizadeh *et al.*, 2018; Armaş, 2012; Banica *et al.*, 2017; Ripepe *et al.*, 2014; Sarris *et al.*, 2010; Zuccaro *et al.*, 2008). L'altezza, in metri, dei singoli edifici è calcolata per differenza tra la quota di gronda e la quota del piano di campagna rilevabile nei layers cartografici, ovvero:

$$I_h = Qg_i - Qc_i \tag{8}$$

Dove:
Qc_i = è la quota del piano di campagna dell'edificio *i*-esimo;
Qg_i = è la quota di gronda dell'edificio *i*-esimo.

Più elevato è l'indice di altezza maggiore è la vulnerabilità sismica dell'edificio.

Indice di vulnerabilità storica

L'indicatore stima, in modo indiretto, la vulnerabilità sismica degli edifici in relazione alle tecniche di costruzione e ai materiali utilizzati. Quest'ultimi influenzano infatti la stabilità strutturale degli edifici (Armač 2012; Guéguen *et al.*, 2007; Rezaie e Panahi, 2015; Zuccaro *et al.*, 2008). Considerato che le tecniche di costruzione ed i materiali utilizzati si sono evoluti nel tempo, apportando progressivi miglioramenti in termini di stabilità statica (Banica *et al.*, 2017; Sarris *et al.*, 2010), è possibile individuare un'omogeneità di tipologie strutturali all'interno di ogni periodo storico. Guidoboni e Ferrari (2000a, 2000b) hanno identificato delle sezioni cronologiche omogenee all'interno delle quali collocare tradizioni costruttive del patrimonio urbanistico italiano. Gli autori propongono una classificazione delle città italiane in cinque periodi storici a partire dal V secolo fino alla prima metà del XX secolo. Tale classificazione si inserisce in un'ottica di analisi sismica territoriale al fine di favorire la rappresentazione di scenari sismici e di ricostruzione post-sismica. Gli autori sostengono che le caratteristiche del patrimonio edilizio italiano derivino da importanti fattori tra i quali: l'epoca storica, che ha visto il prevalere di determinate tecniche costruttive anche grazie agli scambi sociali e culturali con popolazioni dominanti o influenti (es. cultura Greca e Etrusca); la localizzazione geografica, che ha favorito l'utilizzo di particolari materiali costruttivi sulla base della disponibilità delle risorse locali. I tessuti urbani che appartengono alla medesima classe temporale sono dunque caratterizzati da una analoga vulnerabilità agli eventi sismici. Il patrimonio edilizio è quindi in parte influenzato da alcune variabili storiche, come materiali e tecniche costruttive, che possono modificare gli effetti attesi di un evento sismico attraverso processi di mitigazione o amplificazione del danno.

Non essendo disponibile un database che definisca tecniche e materiali da costruzione per ogni edificio presente nell'area di indagine, si è giunti alla stima di tali parametri a partire da due fonti di dati. Da un lato l'archivio di 44 edifici localizzati in Garfagnana, censiti come Edifici pubblici strategici e rilevanti nelle aree soggette a rischio sismico, per i quali sono disponibili indagini strutturali ap-

Tabella 1. Indice di vulnerabilità storica discreto normalizzato (fonte: nostra elaborazione).

Periodo di costruzione edifici	Anno di riferimento	Indice vulnerabilità storica	Indice normalizzato
$P_1 < 1954$	1954	4.58	1
$1954 \leq P_2 > 1978$	1967	2.59	0.56
$1978 < P_3 \geq 1996$	1987	1.07	0.23
$P_4 > 1996$	1998	0.66	0.14

profondite che identificano tecniche e materiali di costruzione e l'epoca di realizzazione dei singoli edifici. Dall'altro lato l'archivio della periodizzazione storica di tutto l'edificato dell'area di studio, ricavato dai dati dei sedimi edilizi della Regione Toscana. Sulla base dei dati disponibili è stato possibile definire una funzione interpolante che esprime, con buona approssimazione (R^2=0.74), l'esistenza di una correlazione tra tipologia costruttiva ed epoca di realizzazione degli edifici (Ripepe *et al.*, 2014). La funzione, che definisce per ogni edificio un indice di vulnerabilità storica, è data da:

$$Ivs_i = 10^{38} \cdot e^{(-0.044 \cdot x_i)} \quad (9)$$

Dove:
Ivs_i = indice di vulnerabilità storica dell'i-esimo edificio;
x_i = anno di costruzione dell'edificio i-esimo.

Per attribuire l'indice di vulnerabilità storica a tutti i poligoni afferenti all'archivio dei sedimi edilizi, è stato fatto riferimento all'anno centrale delle due classi di periodizzazione 1954-1978 e 1978-1996, mentre per la classe inferiore e superiore sono stati presi a riferimento gli anni limite (1954 e 1996) (Tabella 1).

4.3.2 Criterio di vulnerabilità morfologica

Numerosi studi dimostrano che la morfologia del terreno influenza la vulnerabilità sismica degli edifici tramite effetti di amplificazione delle onde sismiche (Costanzo *et al.*, 2016; Nguyen e Gatmiri, 2007; Pessina e Fiorini, 2014; Sarris *et al.*, 2010; Walker *et al.*, 2014). Per classificare il territorio secondo il fattore di amplificazione topografica l'UE ha definito l'European Technical Code (EC8)[16], che individua quattro tipologie morfologiche con grado di amplificazione sismica progressivamente crescente da T1 a T4, impiegate nel presente studio per definire il criterio di vulnerabilità morfologica. Il procedimento di classificazione si basa sullo sviluppo delle seguenti fasi:

[16] Normativa europea: UNI EN 1998-1.

(1) Elaborazione di mappe tramite Topographic Position Index (TPI) per il territorio esaminato:
   (a) Elaborazione mappa TPI per aree circolari di piccole dimensioni (r=50m);
   (b) Elaborazione mappa TPI per aree circolari di grandi dimensioni (r=450m);
(2) Classificazione del territorio secondo le categorie della Landform Classification (Weiss, 2001);
(3) Classificazione del territorio secondo la normativa EC8:
   (a) Elaborazione mappa delle pendenze medie per aree circolari di 100 m;
   (b) Elaborazione mappa delle pendenze massime per aree circolari di 100 m;
   (c) Classificazione tramite EC8 sulla base di: Landform classification; Pendenza media; Pendenza massima.

Elaborazione mappe TPI per il territorio esaminato

Il TPI è un operatore focale il cui algoritmo si basa sull'analisi di dati cartografici raster. In particolare nel presente studio il TPI analizza i dati di una finestra mobile circolare e definisce il valore del pixel centrale in funzione dei valori dei pixels situati nel suo intorno (Jenness, 2006). L'utilizzo del TPI risulta particolarmente efficace per aree di studio non troppo estese e con caratteristiche territoriali eterogenee come il caso della Garfagnana (De Reu *et al.*, 2013; Lucchesi *et al.*, 2007; Monacci e Lucchesi, 2010; Pessina e Fiorini, 2014). Formalmente, l'indicatore TPI per un area di raggio R, è dato da:

$$TPI(R) = \frac{H_c - H_{avg}}{H_{std}} * 100 + 0.5 \quad (10)$$

Dove:
H_c = quota del pixel centrale del kernel[17];
H_{avg} = quota media dei pixel inclusi nell'area circolare attorno al pixel centrale;
H_{std} = deviazione standard delle quote dei pixel inclusi nell'area circolare attorno al pixel centrale.

Il valore del TPI risente dell'ampiezza della finestra mobile (kernel) ed è per questo che la metodologia prevede la comparazione di due finestre di diversa ampiezza (Weiss, 2001). In generale valori positivi del TPI indicano che il punto centrale si trova più in alto rispetto all'ambiente medio circostante, mentre valori negativi del TPI indicano una posizione più bassa rispetto alla aree attigue.

Classificazione del territorio secondo categorie della Landform Classification

Per definire le tipologie secondo la Landform Classification la procedura prevede il calcolo di due TPI per aree di ampiezza diversa. Nel caso specifico, è stato

[17] Il kernel o neighborhood, rappresenta una finestra di ampiezza standard (es. 5x5 pixel se quadrata) rispetto alla quale l'operatore focale effettua le elaborazioni. La finestra, dopo ogni elaborazione, si muove sul layer raster da sinistra verso destra e dall'alto verso il basso, elaborando la totalità dei dati raster del territorio esaminato.

Tabella. 2. Criteri per la classificazione del territorio in Landform categories (fonte: Jenness, 2006).

Landform categories	Small neighborhood (raggio 50 mt)	Large neighborhood (raggio 450 mt)	Slope
canyons, deeply incised streams	TPI ≤ -1	TPI ≤ -1	-
midslope drainages, shallow valleys	TPI ≤ -1	-1 < TPI < 1	-
upland drainages, headwaters	TPI ≤ -1	TPI ≥ 1	-
u-shaped valleys	-1 < TPI < 1	TPI ≤ -1	
plains small	-1 < TPI < 1	-1 < TPI < 1	≤ 5°
open slopes	-1 < TPI < 1	-1 < TPI < 1	> 5°
upper slopes, mesas	-1 < TPI < 1	TPI ≥ 1	-
local ridges, hills in valleys	TPI ≥ 1	TPI ≤ -1	-
midslope ridges, small hills in plain	TPI ≥ 1	-1 < TPI < 1	-
mountain tops, high ridges	TPI ≥ 1	TPI ≥ 1	-

calcolato il TPI rispetto a due finestre mobili circolari: una con raggio di 50 metri e una con raggio di 450 metri[18] (Tagil e Jenness, 2008). Dalla combinazione delle mappe dei due TPI e della mappa delle pendenze è stato possibile classificare il territorio secondo le 10 Landform categories definite da Weiss nel 2001 e aggiornati da Jenness nel 2006 (Tabella 2).

Classificazione del territorio secondo l'European Technical Code (EC8)

Per classificare il territorio secondo il fattore di amplificazione topografica definito dal Codice EC8 si è proceduto secondo la metodologia proposta da Costanzo *et al.* nel 2016. La classificazione è avvenuta analizzando congiuntamente la mappa della Landform Classification e le mappe delle pendenze medie e massime realizzate con finestre mobili circolari di 100 m di raggio (Costanzo *et al.*, 2016) seguendo i criteri illustrati in Tabella 3.

4.3.3 Criterio di vulnerabilità urbana

Numerosi studi sulla vulnerabilità sismica territoriale hanno evidenziato che la densità delle strutture e infrastrutture urbane rappresenta un fattore che influenza la vulnerabilità sismica a scala territoriale (Hizbaron *et al.*, 2012; Rezaie e Panahi, 2015). Allo scopo di computare tali effetti nel modello di valutazione della VST

[18] Le dimensioni delle finestre mobili (neighbourhood) sono state definite sulla base dei risultati di uno studio effettuato dall'Università di Balikesir in Turchia (Tagil & Jenness, 2008). Lo studio, realizzato su un territorio con caratteristiche morfologiche analoghe alla Garfagnana, ha infatti conseguito risultati molto rappresentativi.

Tabella 3. Criteri per la valutazione della classe di amplificazione topografica secondo l'European Technical Code (EC8) (fonte: nostra rielaborazione da Costanzo *et al.*, 2016).

Landform category	Pendenza media	Pendenza max	EC8 Class	Indice normalizzato
mountain tops, high ridges local ridges, hills in valley upper slopes, mesas	-	≥ 30°	T4	1
mountain tops, high ridges local ridges, hills in valley upper slopes, mesas	-	≥ 15°	T3	0.75
midslope ridges, small hills in plains open slopes	≥ 15°	-	T2	0.50
mountain tops, high ridges local ridges, hills in valley upper slopes, mesas	-	<15°	unclassified	-
other	-	-	T1	0.25

sono stati determinati due indicatori capaci di misurare sia il livello di congestione urbana che il grado di carenza viaria.

Indice di vulnerabilità da congestione urbana

La densità urbana incide profondamente sugli effetti di un evento sismico (Armaş, 2012; Banica *et al.*, 2017; Rezaie e Panahi, 2015; Sarris *et al.*, 2010). Innanzitutto l'elevata densità dell'edificato è implicitamente connessa alla presenza di un'alta concentrazione di popolazione che può essere messa a rischio; inoltre, la compattezza degli edifici determina una maggiore difficoltà nella gestione dell'emergenza in termini di accesso e facilità delle operazioni. Per cercare di valutare tali aspetti è stato predisposto un indicatore che fa riferimento alla spacematrix di Berghauser Pont e Haupt (2007). Il metodo si basa su due indicatori (Figura 5): l'indice di superficie occupata (GSI – Ground Space Index) e l'indice di superficie costruita (FSI – Floor Space Index) che vengono valutati su unità urbanistiche elementari (lotti, isolati o distretti) (de Jong, 2011). Formalmente, i due indicatori sono così definiti:

Si è ritenuto opportuno strutturare un indicatore che consideri la combinazione dei due indici, definendo degli isoquanti di Vulnerabilità Sismica Urbana (es. VCU0,1; VCU0,4; VCU0,7 in Figura 6). Ciascun isoquanto è definito dal prodotto dei due indici, per cui formalmente avremo:

$$VCU_i = FSI_i \cdot GSI_i \qquad (11)$$

Figura 5. Indicatori FSI e GSI (fonte: De Jong, 2011).

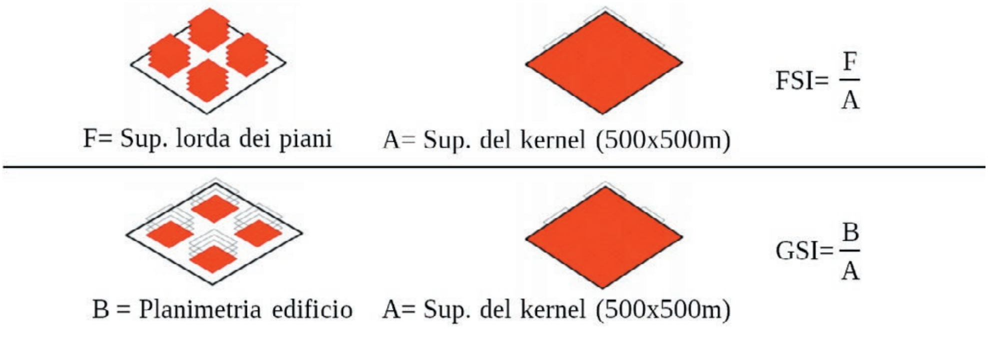
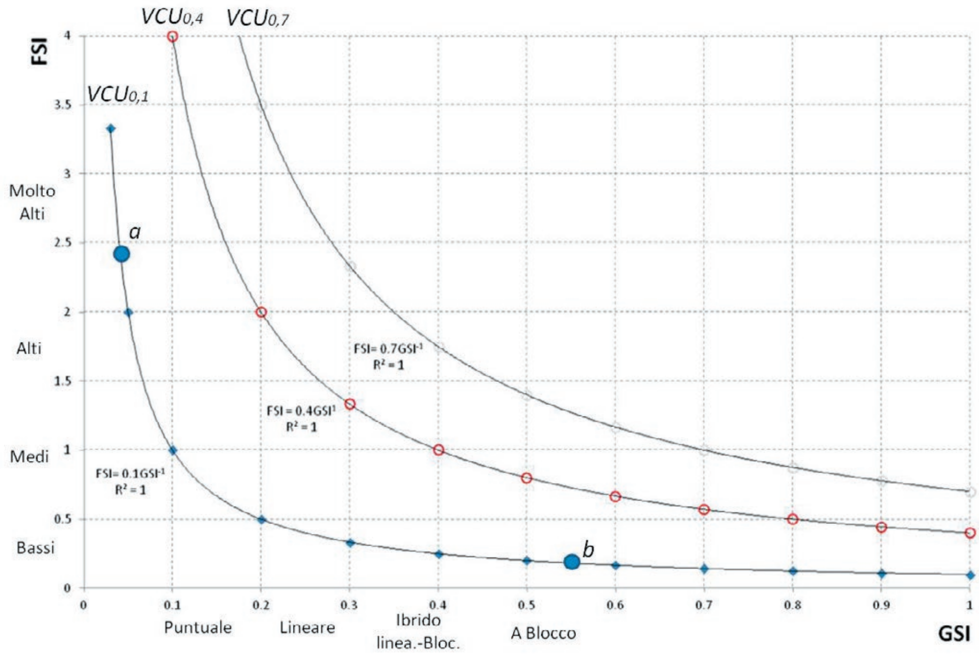


Figura 6. Esempio di Indice di Vulnerabilità da Congestione urbana al variare di GSI e FSI (fonte: nostra rielaborazione da De Jong, 2011).



Dove:
VCU_i = Vulnerabilità da congestione urbana del kernel *i*-esimo.

Le unità urbanistiche in questo caso sono valutate attraverso un kernel mobile di dimensioni 51x51 pixel (510x510m), in cui l'operatore focale stima il rapporto F/A dei pixels inclusi, per la stima di FSI, e il rapporto B/A dei pixels inclusi, per la stima di GSI.

Indice di vulnerabilità da carenza viaria

Uno dei criteri che incide maggiormente sulla vulnerabilità sismica di un territorio è rappresentato dalla presenza di viabilità e spazi aperti circostanti gli edifici, nonché dalla loro ampiezza (Hizbaron *et al.*, 2012). In caso di evento sismico tale infrastruttura è infatti funzionale a garantire la rapida evacuazione della popolazione e la presenza di spazi sicuri in cui rifugiarsi, come pure il facile raggiungimento da parte dei mezzi d'emergenza (Bono e Gutiérrez, 2011). Per questo è stato definito un indice di densità viaria che valuti non solo la concentrazione della rete stradale, ma anche la tipologia di rete, ovvero la sua larghezza e capacità di flusso. Pertanto, grazie alla CTR 1:10.000 della Regione Toscana è stato possibile produrre una mappa raster della viabilità con quattro classi[19]:

- classe 0: assenza di viabilità;
- classe 1: strada con larghezza inferiore a 3.5 metri;
- classe 2: strada con larghezza compresa tra 3.5 e 7 metri;
- classe 3: strada con larghezza superiore a 7 metri.

L'indice di densità viaria è stato quindi definito attraverso un operatore focale con kernel di 34x34 pixel (340x340m), in cui l'operatore stima la media dei valori dei pixels inclusi. Formalmente:

$$\bar{x}_j = \max v - \frac{1}{n} \cdot \sum_{i=1}^{n} x_{v,j} \qquad v = \{0,1,2,3\} \tag{12}$$

Dove:

$\bar{x}_j$ = indice di vulnerabilità da densità viaria del pixel *j*-esimo;

$x_{v,j}$= valore della classe *v*-esima per il pixel *j*-esimo;

n = numero di pixels del kernel.

Un'area servita da un elevato numero di strade di classe 3 avrà una minore vulnerabilità sismica viaria rispetto a una zona servita da un ridotto numero di strade di classe 1.

5. Risultati

L'analisi delle gerarchie (AHP) ha evidenziato la particolare rilevanza dell'indice storico (w=0.355) nella definizione del criterio strutturale (Tabella 4). Per i professionisti e gli studiosi coinvolti nell'indagine assumono quindi un ruolo particolarmente importante i materiali e le tecniche costruttive, mentre risulta meno rilevante l'isolamento dell'edificio (w=0.106) (Tabella 4). La valutazione rispetto ai parametri urbanistici evidenzia una particolare importanza del fattore di congestione urbana (w=0.667) rispetto alla presenza di infrastrutture viarie (Tabella 5). Infine, per quanto attiene i macrocriteri (strutturale, urbanistico e morfologico) il criterio che assume la maggiore importanza è quello strutturale (w=0.556), a con-

[19] Ai pochi segmenti stradali di cui non era stata rilevata alcuna dimensione è stata assegnata la classe 1.

Tabella 4. Pesi criteri di terzo livello: criterio di vulnerabilità strutturale (fonte: nostra elaborazione).

Criteri	Pesi attribuiti dai singoli esperti						Pesi globali (media geometrica)
	esperto 1	esperto 2	esperto 3	esperto 4	esperto 5	esperto 6	
Iv storica	0.330	0.498	0.282	0.059	0.262	0.326	0.355
Iv ipsometrico	0.318	0.111	0.256	0.332	0.343	0.177	0.279
Iv forma perimetrale	0.152	0.249	0.226	0.308	0.204	0.317	0.260
Iv isolamento	0.200	0.142	0.236	0.302	0.191	0.180	0.106
Indice di consistenza	0.063	0.098	0.042	0.069	0.088	0.056	

Tabella 5. Pesi criteri di terzo livello: criterio di vulnerabilità urbana (fonte: nostra elaborazione).

Criteri	Pesi attribuiti dai singoli esperti						Pesi globali (media geometrica)
	esperto 1	esperto 2	esperto 3	esperto 4	esperto 5	esperto 6	
Iv carenza viaria	0.670	0.550	0.650	0.150	0.310	0.610	0.333
Iv congestione urbana	0.330	0.450	0.350	0.850	0.790	0.390	0.667

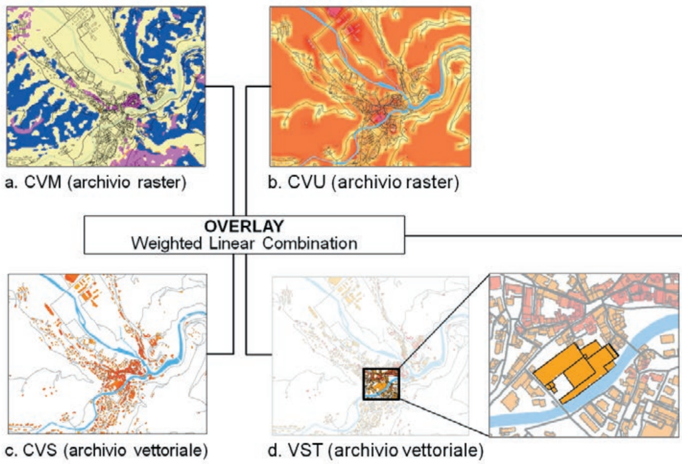
Tabella 6. Peso criteri di secondo livello (fonte: nostra elaborazione).

Criteri	Pesi attribuiti dai singoli esperti						Pesi globali (media geometrica)
	esperto 1	esperto 2	esperto 3	esperto 4	esperto 5	esperto 6	
Cv strutturale	0.402	0.296	0.439	0.320	0.400	0.368	0.556
Cv morfologica	0.319	0.364	0.314	0.384	0.341	0.280	0.301
Cv urbano	0.279	0.340	0.247	0.296	0.259	0.353	0.143
Indice di consistenza	0.038	0.017	0.057	0.025	0.034	0.021	

ferma del fatto che per gli esperti tali parametri sono prevalenti ai fini della definizione della vulnerabilità sismica rispetto ai parametri morfologici (w=0.301) e urbani (w=0.143) (Tabella 6).

I risultati delle elaborazioni su base GIS hanno portato alla realizzazione: di un archivio vettoriale, rappresentato dalla mappa di vulnerabilità sismica strutturale (Figura 7c); di due mappe raster, rappresentate dalla vulnerabilità sismica morfologica (Figura 7a) e dalla vulnerabilità sismica urbana (Figura 7b). L'ultima aggregazione è stata eseguita tra archivi vettoriali, previa assegnazione dei contenuti delle due mappe raster a una mappa vettoriale dell'edificato. In tale modo è stato possibile procedere alla somma pesata dei layers vettoriali rappresentativi dei tre macrocriteri.

Figura 7. Mappe relative a: (a) criterio di vulnerabilità morfologica; (b) criterio di vulnerabilità urbana; (c) criterio di vulnerabilità strutturale; (d) indicatore di vulnerabilità sismica territoriale (fonte: nostra elaborazione).



Classe VST	MEDIA
Cv strutturale (1)	0.57
(1) Iv isolamento	0.79
(1) Iv forma planimetrica	0.87
(1) Iv ipsometrica	0.53
(1) Iv storica	0.23
Cv morfologica (2)	0.25
Cv urbana (3)	0.51-0.74
(3) Iv congestione urbana	0.49-0.63
(3) Iv carenza viaria	0.33-1

Il risultato finale è costituito da una mappa vettoriale della VST nella quale ad ogni poligono, che rappresenta un edificio, è attribuito un database di informazioni relative al valore assunto dai diversi criteri di secondo e terzo livello e dalla VST complessiva (Figura 7d). Per rendere facilmente interpretabile il risultato agli stakeholders si è quindi proceduto ad una riclassificazione dell'edificato secondo quantificatori linguistici basati su tre classi qualitative: bassa, media e alta vulnerabilità. Per questo si è fatto riferimento alle funzioni di appartenenza proposte da Bernetti e Fagarazzi nel 2002 per la conversione, in termini linguistici, di valori normalizzati nell'intervallo [0,1]. Per tale conversione è stato impiegato il metodo di Chen e Hwang (1992) con i seguenti range:

- classe 1 - vulnerabilità bassa: valori minori di 0.385;
- classe 2 - vulnerabilità media: valori compresi tra 0.385 e 0.615;
- classe 3 - vulnerabilità alta: valori maggiori di 0.615.

Sulla base dei risultati emerge che gli edifici ad alta VST sono pari a 490, rappresentano quasi il 2% del patrimonio edilizio complessivo dell'area di studio e sono collocati principalmente all'interno dei nuclei urbani storici. Gli edifici cui è attribuito un livello medio di VST sono pari a 10˙196 e rappresentano circa il 40% dell'edificato. Nel contesto della Garfagnana infine sono presenti 14˙873 edifici a bassa VST, pari a oltre il 58% dell'edificato dell'area (Tabella 7).

6. Discussione e conclusione

Il presente studio propone una metodologia di valutazione della vulnerabilità sismica territoriale (VST) dei singoli edifici in relazione alle specifiche caratteri-

Tabella 7. Numero di edifici per classe di Vulnerabilità Sismica Territoriale divisi per Comune (fonte: nostra elaborazione).

Comune	N° edifici per classe VST			Edifici totali per Comune
	Bassa	Media	Alta	
Camporgiano	1˙282	902	26	2˙210
Careggine	427	149	0	576
Castelnuovo di Garfagnana	1˙847	1.399	111	3˙357
Castiglione di Garfagnana	887	788	43	1˙718
Fabbriche di Vallico	425	332	12	769
Fosciandora	298	563	31	892
Gallicano	1˙682	1˙324	86	3˙092
Giuncugnano	410	45	0	455
Minucciano	1˙431	106	0	1˙537
Molazzana	615	706	24	1˙345
Piazza al Serchio	1˙464	688	15	2˙168
Pieve Fosciandora	1˙021	636	20	1˙677
San Romano in Garfagnana	851	782	21	1˙654
Sillano	564	311	12	887
Vagli Sotto	584	249	14	847
Vergemoli	296	490	30	816
Villa Collemandina	789	726	45	1560
Edifici totali per classe VST	14˙873	10˙196	490	25˙560

stiche strutturali e all'organizzazione spaziale e funzionale del sistema urbano. Si tratta di una proposta che può rappresentare un valido strumento di supporto per realizzare rapidi screening di tutto il patrimonio edilizio situato su ampi territori sismici. La puntuale classificazione dei singoli edifici permette infatti di individuare, su ampi contesti, le strutture più sensibili dal punto di vista sismico. Per esse sarà possibile programmare indagini più approfondite ed eventuali politiche di incentivazione degli interventi antisismici.

I risultati conseguiti su uno specifico ambito territoriale, hanno infatti permesso l'identificazione di nuclei storici caratterizzati da elevata vulnerabilità strutturale. Si tratta di aree ad elevata criticità conseguenti a molteplici fattori, tra questi: (i) presenza di edifici antichi (Indice di vulnerabilità storica elevato), (ii) altezze mediamente superiori ai 9 metri (Indice di vulnerabilità ipsometrica elevato) e (iii) disposizione aggregata prevalente (Indice di vulnerabilità di isolamento elevato). A tali aspetti si associano poi condizioni morfologiche particolarmente sfavorevoli dovute alla localizzazione degli edifici in corrispondenza di poggi o alture che amplificano la vulnerabilità ad eventi sismici. L'esame specifico dei risultati conseguiti nei centri storici[20] ha evidenziato che oltre il 60% degli edifici situati in tali contesti presentano VST media o alta. In particolare, per tali edifici sono stati registrati elevati valori di vulnerabilità strutturale (variabili tra 0.5 e 0.83). Viceversa, le strutture edilizie più recenti, realizzate dopo il 1978, siano esse di carattere residenziale o industriale, oltre a presentare una minore vulnerabilità strutturale (variabile tra 0.11 e 0.57) si collocano anche in contesti morfologici e urbanistici che non amplificano la vulnerabilità sismica (pianura e collina).

Un punto critico del modello è sicuramente rappresentato dall'esigenza di acquisire archivi vettoriali con elevata qualità geometrica. L'applicazione, pur lavorando su ampia scala cartografica, mira a classificare i singoli manufatti edili; di conseguenza, le geometrie dovrebbero rappresentare piuttosto fedelmente la realtà territoriale. Attualmente, negli archivi vettoriali disponibili presso le PP.AA. sono invece rilevabili errori, soprattutto nelle aree a maggiore concentrazione di edifici, come i nuclei storici urbanizzati. In questi contesti è stato rilevato che nelle carte tecniche regionali, anche in scala 1:10˙000, sono spesso presenti geometrie aggregate invece di poligoni suddivisi da vie pedonali di piccole dimensioni. In questi casi la vulnerabilità di forma planimetrica risulta sovrastimata a causa dell'articolazione complessa del poligono e anche la vulnerabilità di isolamento tende a valori elevati. A questo si aggiunge il fatto che il grafo stradale della Regione Toscana presenta alcuni tratti stradali senza classificazione dimensionale, ai quali è stato necessario attribuire, in via cautelativa, la classe dimensionale minore. Un ulteriore punto da approfondire risulta essere l'aspetto di natura strettamente architettonica legato ai materiali costruttivi, la cui influenza sull'effetto dell'evento sismico risulta rilevante (Alizadeh *et al.*, 2018; Banica *et al.*, 2017; Barbat *et al.*, 2009; Sarris *et al.*, 2010; Zuccaro *et al.*, 2008). La funzione di correlazione tra l'epoca di realizzazione del manufatto edilizio e la tecnica di costruzione impiegata (Indice di vulnerabilità storica), rappresenta tuttavia un'efficace strategia per un'analisi di tipo speditivo, quale quella proposta nel presente modello d'indagine. In assenza di informazioni dettagliate risulta infatti utile poter sviluppare strategie d'indagine che valorizzino gli archivi pubblici già disponibili, riducendo tempi e risorse necessarie per studi di dettaglio sui singoli edifici. Per migliorare la valutazione di tale aspetto sarebbe quindi auspicabile un'integrazione del modello con una specifica indagine campionaria sui materiali del patrimonio edilizio regionale e sui corrispondenti periodi di costruzione. Al riguardo esistono alcuni esempi di questo tipo d'indagine tra i quali quello di Arrighetti del 2016 sull'archeologia architettonica e quello di D'Ayala e Speranza del 1999 sulla meccanica strutturale. L'elevata qualità, affidabilità e completezza degli strati informativi utilizzati nella valutazione è quindi un prerequisito indispensabile per lo sviluppo di un modello rappresentativo, in grado di giungere ad una classificazione puntuale di ogni singolo edificio presente nel territorio di indagine.

[20] Sono stati considerati appartenenti ai centri storici gli edifici presenti all'interno di un'areale di 150 mq a partire dal baricentro dei poligoni rappresentanti i tessuti urbani ad impianto storico geolocalizzati nel territorio di studio.

Con le dovute integrazioni la metodologia proposta può quindi rappresentare un importante strumento di supporto per i diversi settori della PP.AA.. I risultati ottenuti, infatti, consentirebbero una collocazione più efficiente delle risorse pubbliche, concentrando le iniziative in contesti urbani sismicamente più critici, dove proporre e supportare l'attuazione di puntuali e approfondite indagini di vulnerabilità sismica. La maggiore conoscenza delle condizioni di vulnerabilità sismica a scala urbana, permetterebbe inoltre un miglioramento dell'organizzazione emergenziale, consentendo sia di individuare edifici e aree urbane potenzialmente più vulnerabili, sia di identificare edifici e aree sicure in cui pianificare punti di raccolta e vie di fuga. Per queste ultime aree sarà possibile definire azioni prescrittive nei piani urbanistici volte a mantenere o addirittura ridurre la loro vulnerabilità.

Grazie a tale metodologia sarebbe quindi possibile estendere le costose valutazioni, attualmente limitate ai soli edifici strategici e rilevanti, anche a tutte le altre categorie edilizie: residenziale, industriale e commerciale. La scelta di combinare parametri prettamente strutturali dei singoli edifici con parametri caratterizzanti la dimensione territoriale permette inoltre di includere nella definizione della vulnerabilità sismica del singolo edificio anche le condizioni di vulnerabilità di tutto il tessuto urbano che lo circonda, fornendo una visione valutativa ampia e coerente delle condizioni reali. Concludendo, è plausibile ipotizzare che il crescente sviluppo delle tecniche di telerilevamento, anche da immagini satellitari, possa colmare gli attuali gap informativi di carattere territoriale (dimensione della viabilità; conformazione dei poligoni edilizi nei centri storici; ecc.). Tale sviluppo, unitamente a quello delle tecnologie informatiche e dell'analisi remota delle tecniche costruttive, potrebbe garantire il raggiungimento di importanti risultati nel campo dell'analisi della vulnerabilità sismica e della pianificazione territoriale.

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Transitioning agri-food systems into circular economy trajectories[§]

Circular Economy (CE) might be the paradigm to re-conceptualize future agri-food industries and recreate a balanced co-existence of ecological and economic systems. Research is then called to find solutions for transitioning into CE. The current paper will apply the theory of socio-technical transitions as a framework to build a step by step procedure to analyze and manage agri-food circular economy transitions and support stakeholders involved. The agro-ecological (cultivation and harvesting), agro-industrial (food processing) and consumption (food purchase) sub-systems of agri-food supply chains are analysed to address the main challenges for the transition into CE. The current paper final goal is to generate an analytical framework, for practitioners and policy makers, to identify suitable technological, market, coordination and regulative solutions to orient future CE trajectories.

1. Introduction

The call to transform industrial systems through a circular economy (CE) model has gained prominence. Circular economy narrative proposes a shift toward a completely new way to satisfy societal needs (Borrello et al., 2020b), based on a clear and direct inspirational meaning: "the way we make things is wrong and we must change it" (Borrello et al., 2020a, p. 4069). Accordingly, scholarly literature has grown exponentially during the last years, proposing technical, managerial, and regulative

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solutions, and approaching crosswise several industrial systems. This paper focuses on the agri-food system, particularly with the goal to generate an analytical framework, for practitioners and policy makers to orient future agri-food CE trajectories.

Current industrial agriculture is based on an extractive model with the exploitation of non-renewable resources (e.g. fossil fuels and mineral phosphate) (Clay, 2013), as well as on the production of relevant amounts of wastes. A circular agri-food system would be based on restorative and regenerative practices, as well as on the commitment of several stakeholders, to mitigate the impact of current industrial agriculture. On the one hand, collaborations within and between the agro-ecological (primary production) and agro-industrial (commercial food production) agri-food subsystems might generate intra/inter-company material metabolisms to maximize the use of the inherent value of resources. On the other hand, CE practices would entail stakeholders' participation, with consumers eventually called to support companies engaged in CE. While nowadays there is plenty of technologies applicable in such type of collaborations, how making these technologies operational within fully functioning intra/inter-sectoral circular economy systems is still unclear (Borrello et al., 2016; Chinnici et al., 2019). Every single loop of a CE system could entail tackling major barriers such as political, legal, economic, social, and technological (Kirchherr et al., 2018) and building a circular agri-food system requires facing several challenges (Borrello et al., 2016). Therefore, once defined different agri-food trajectories (e.g. restorative in-farm practices vs. broader bio-economy utilizations) (Stegmann et al., 2020), facing these challenges is crucial to define which of these trajectories would be the most effective.

To this aim, the current paper provides an analytical framework for transitioning into circular agri-food systems, thus contributing to the field of inquiry of sustainable transitions management (Smith et al., 2005). Circular agri-food trajectories require extant supply chains to be adapted to CE principles (transitioning). Putting this differently, a CE model means to build on existent production-consumption systems to create an economy that "contribute to all the three dimensions of sustainable development", that limits material and energy throughout flow "to a level that nature tolerates" and "utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates" (Korhonen et al., 2018, p.39). Resting on this assumption, the paper adopts as theoretical foundations a consolidated model of socio-technical transitions, i.e., the multilevel perspective (MLP) by Geels (2002, 2019). According to the MPL, transitioning socio-technical regimes go through a process by which niche innovations replace stabilized systems, mediated also by macrolevel (landscape) requirements and transformations. This process represents the background framework of this research. Even though in the future circular niche innovations are expected to undergo this process thanks also to landscape perturbations (e.g., the current COVID-19 pandemic caused also by conflicts in the human-environment interface, Zhou et al., 2020), an effective transition to circular agri-food systems should be governed, monitored (to verify the implementation of actually beneficial solutions) and stimulated (Smith et al., 2005). Therefore, the goal of this paper is to suggest a multi-step analytical guiding framework for managing transitions into agri-food CE systems. More specifically, the paper adapts the framework proposed by Gorissen and colleagues (2016) to the context of agri-food systems. As it will be shown further by means of the elaboration of each step of the framework, the governing transition starts from the study of the existing linear system at hand, identifying knowledge gaps and lock-ins for the transition to a circular counterpart. This analysis allows also to identify circular pioneers and closed-loop innovations to consider in the transition process. Starting from this initial assessment, the paper suggests the valuation and comparison of suitable transition trajectories from the ecological, social, and economic perspectives, thus addressing all the three sustainability pillars.

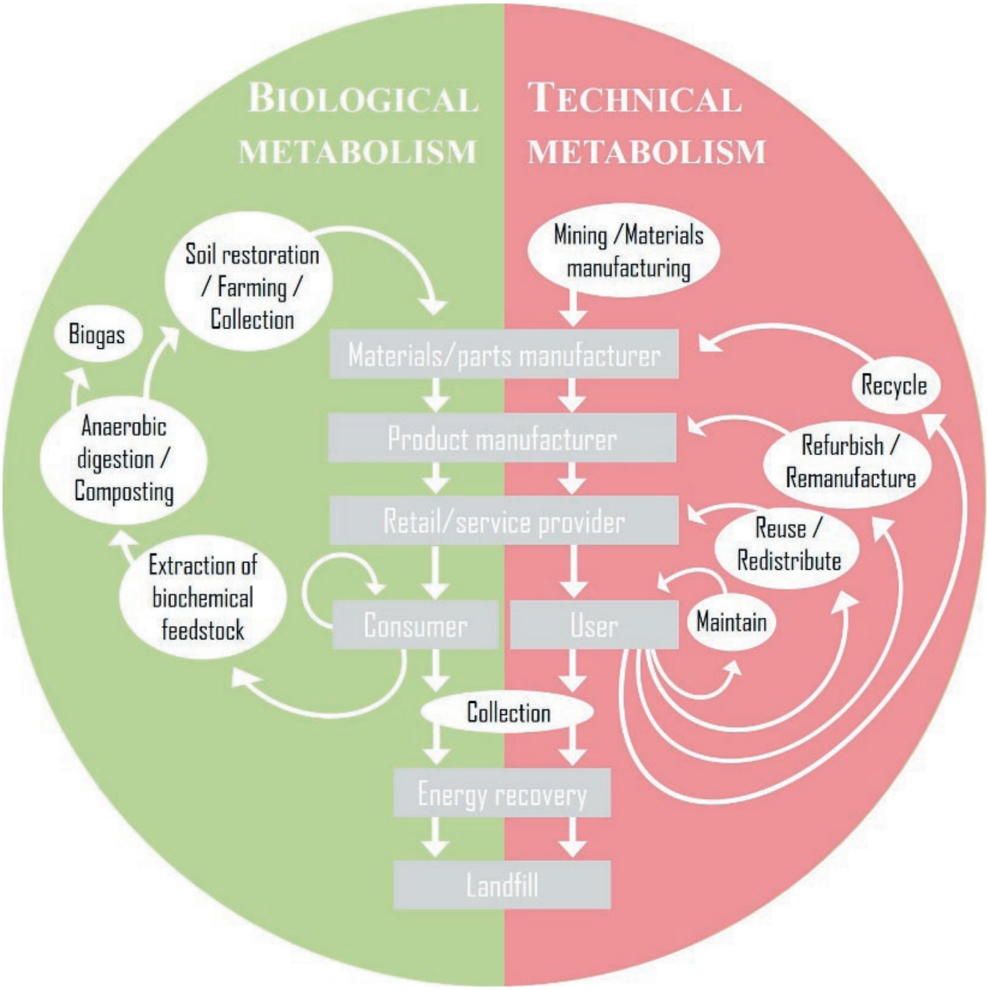
This paper contributes to the existing literature by providing a set of guidelines on how approaching to agri-food circular economy transitions. The great potential of the CE narrative is that stimulates the creation of novel industrial solutions by design (EMF, 2012). Political efforts are currently pushing investments and research in this direction, lately with actions included in the recent Horizon 2020-funded European Green Deal Call (e.g., the call LC-GD-3-2-2020: Demonstration of systemic solutions for the territorial deployment of the circular economy). However, building new intra/intersectoral collaborations based on closed-loop metabolisms is not an easy task, as well as assessing their desirability is not trivial. The following sections seek to provide instructions on how approaching systematically to this challenge.

2. Literature review

2.1 Theoretical background on circular economy

The fast changes occurred after the industrial revolution have conveyed a dualistic representation of ecological and economic systems (Heikkurinen et al., 2016). Rather than supporting a worldview in which economy is a subset of the environment — that is, arguably, “the way things really are” (Gibson, 2001, p.11) — current economic system exploits ecosystems, nowadays reduced to ‘source’ and ‘sink’ of resources and wastes needed to foster economic growth. Circular Economy (CE) is the latest policy and academic approach to address this current and long-standing issue (*e.g.*, European Commission, 2015; Lieder and Rashid, 2016; Sauvé et al., 2016; Murray et al., 2017). CE narrative posits a paradigm of economic development in which economic growth and natural resource consumption are decoupled (UNEP, 2011; Ghisellini et al., 2016) and where, thanks to regenerative and restorative industrial design (Morseletto, 2020), the traditional “take-make-dispose” linear pattern of resource consumption is abandoned (EMF, 2012). A CE model would extend the life cycle of materials, making the waste of one industry the input of the same or another industry and thus maximizing the utilization of the value embedded in them (*cf.* the industrial ecology concept and the life’s principle “waste=food”; Frosch and Gallopoulos, 1989; Benyus, 2002). Furthermore, it would generate economic value from waste produced at each

Figure 1. Metabolisms in the Circular Economy.



Source: Borrello et al. (2020a), adapted from EMF (2012).

stage of supply chains, including post-consumption (Fischer and Pascucci, 2017). According to the CE framework proposed by the Ellen MacArthur Foundation (EMF, 2012), two types of materials constitute the current industrial system: biological and technical nutrients (Fig. 1). While biological nutrients are biodegradable and can re-enter natural metabolisms (Smol et al., 2015), technical ones follow technical metabolisms through reuse, remanufacture or material recovery (Tukker, 2015). The current paper concerns biological nutrients, more specifically focusing on the agri-food system.

In biological metabolisms, CE aims at maximizing the value generated from biological nutrients through different practices and technologies, contributing to prevent and effectively manage wastes and by-products (Mohan et al., 2016). Biological nutrients are assumed to flow from one company to another, imitating (*i.e.* complying with) the processes of organic mineralization-synthesis occurring in biological ecosystems. Undergoing cascades of consecutive industrial processes, biological nutrients can be processed to produce biochemicals and biomaterials and then fuel biogas plants to produce energy and digestate. Furthermore, regenerative agricultural practices can valorise agricultural losses and residues in-farm.

Even though a set of attributes of a CE system seems to be widely accepted by scholars, "there remains a lack of clarity about what "circular" actually means in practice" (Gladek, 2019). Several efforts have been made so far to devise a suitable definition of CE. To illustrate the extent of current conceptual endeavour, Kirchherr et al. (2017) gathered from the scholarly literature 114 definitions of CE. While some authors "seem to have no idea about what [CE] is" (Kirchherr et al., 2017, p.229), others argue that it is not clear yet in which way it differs from sustainability and which type of relationship occurs between the two concepts (Geissdoerfer et al., 2017). One interpretation of the latter issue is the one suggested by Sauvé et al. (2016). According to these authors, sustainability has broader societal objectives compared with circular economy. However, CE is a tool for sustainability, based on reshaping production and consumption models, that gives "a clear angle of attack to help solving environmental problems" (ibid., p. 55). In a nutshell, CE is a way to achieve sustainability, that proposes a set of solutions (e.g., cradle-to-cradle processes, industrial symbiosis, replacing downcycling with upcycling, circular business models). Starting from their implementation by pioneering innovators at niche level, these solutions are expected to replace in the future well-established linear systems, after having undergone a transition process.

2.2 A brief overview of transition theory

The theory on socio-technical transitions (Geels, 2002, 2010, 2019; Smith et al., 2005) explicitly addresses issues related to the dynamics of change. It defines a transition as a transformation, often radical, in response to a "… a number of persistent problems confronting contemporary modern societies" (Grin et al., 2010, p. 1). To illustrate, a transition requires disruptive changes "in the ways of organizing (structures), ways of thinking (cultures) and ways of doing (practices)" (Gorissen et al., 2016, p.3). Literature shows a great interest in this field of inquiry providing different lenses to increase the operational aspects of transitions. Among these: the multilevel perspective, where interactions are mainly seen between scales; the multiphase perspective, where the development is seen between phases; and the multipattern perspective, that describes how a transition is possible thanks to different patterns (Rotmans, 2012).

Applying transition theory to the CE, the common idea emerging from the different perspectives is that circular innovations should propagate and substitute

Table 1. Guiding framework with elements to consider for a transition management.

Type	Description
Analyzing the system	Understand how the current systems functions, what does and what does not work, what is appropriate and what is not
Envisioning	Imagine how we would like the future system to look like and function, what is desirable, what is sustainable
Exploring trajectories	Explore how we can evolve from the current situation to the envisioned system and what trend breaks are required
Experimenting	Explore how the chosen trajectories can be translated into practical actions and how the trend breaks can be induced
Assessing	Monitor the transition process through follow-up and reflection on all actions, events, policies and strategies that influence the transition in question; and hence feed a process of social learning, which is a prerequisite for eventual success
Translating	Translate the lessons learnt into change-inducing actions in order to incrementally transform ("transitionize") the system, closer to a dynamic sustainable equilibrium

Source: adapted by Gorissen et al., 2016.

linear solutions (Borrello et al., 2020a). Putting this differently, a socio-technical transition into CE in different industrial systems would entail the emergence of several incremental processes of innovations at niche level (*i.e.*, transition trajectories), that would eventually lead to replacing the linear way to fulfil societal needs (cf., Kwakkel and Yücel, 2014). Among the three approaches mentioned above, transition trajectories are best described by the multilevel perspective (MLP) (Geels, 2002). The MLP focuses on how sustainable configurations change over time from a continuous interaction among processes at niche level (radical innovations promoted by pioneer activities), system level (technical, political, social, and cultural, business models or infrastructural configurations), and landscape level (e.g., demographics, cultural repertoires, societal concerns, geopolitics, macroeconomic trends, ecological dynamics, wars, financial crises, and oil prices shocks) (Geels, 2002, 2019; Borrello et al., 2020a). The way it is supposed to operate is illustrated by Geels (2019, p.190): "(a) niche-innovations gradually build internal momentum, (b) niche innovations and landscape changes create pressure on the system and regime, and (c) destabilization of the regime creates windows of opportunity for niche-innovations, which then diffuse and disrupt the existing system."

According to the MLP, "transition management takes a process approach that aims to change the dominant culture, structures and practices of unsustainable systems by linking innovations at the microlevel to macrolevel changes in mindsets" (Loorbach et al., 2010, p.137). Since a change involves a wide spectrum of actors (*i.e.*, companies, governments, researchers, etc.), a governance perspective is needed to analyze processes of transformation aiming at developing strategies to accelerate the transition. Gorissen and colleagues (2016) suggest a combination of mutually reinforcing operational steps and activities related to the transition management (Tab. 1). These activities constitute a guiding framework rather than a chronological sequence of steps. The current paper describes specific activities adapting these indications to a specific industrial sector, namely agri-food systems.

3. Analytical framework

3.1 Analyzing the system

The first step of the guiding framework of Gorissen and colleagues (2016) following this logic has suggested understanding the current system and its functions, with the definition of challenges and lock-ins that make the transition slow or not observable at all. Most of agri-food supply chains may be conceptualized as a three-block system constituted by primary production (agro-ecological subsystem), commercial food production (agro-industrial subsystem) and consumption (Fig. 2).

Starting from this configuration a number of challenges can be identified for transitioning into a CE model (Tab. 2). To illustrate, each subsystem has to face four main challenges preventing the adoption of circular strategies, namely technological, market, coordination and regulatory. The four challenges are derived adapting and summarizing the contents of two recent papers concerning CE challenges (Borrello et al., 2016 and Kirchherr et al., 2018), thus being generalizable to a great extent. The challenges presented are generated by different issues per each subsystem (Tab. 3). The challenges are the following:

- Technological: both farms and processing companies use technologies and practices often conflicting with CE principles (*e.g.*, Løes and Adler, 2019). Transitioning into CE might not be easy depending on different factors (*e.g.*, farm structure, farm size). Furthermore, assuming different CE trajectories, it is not sure what would be their impact, as well as which trajectory would significantly improve the *status quo*. As it will be better explained later, this issue requires specific impact assessments of different technology implementation scenarios.
- Market: transitioning into CE entails new ways of doing business in the agro-ecological and agro-industrial subsystems. Circular business models (CBMs), in which value creation is based on maximizing the economic value of materials, must be adopted (Lewandowski, 2016; Linder and Williander, 2017). Although consumers are increasingly interested in non-hedonistic aspects of food (Giannoccaro et al.,

Figure 2. Stylized configuration of agri-food supply chains.

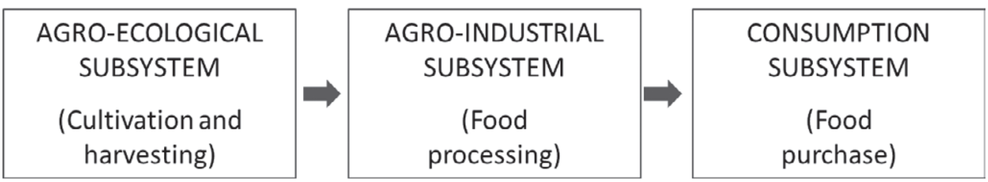


Table 2. Challenges for the transition into agri-food circular systems.

Supply chain subsystems	Challenges			
	Technological	Market	Coordination	Regulatory
Agro-ecological	- Adoption of circular farming technologies and practices;	-Adoption of circular business models	- Farmers' willingness to participate to CE trajectories;	- Obstructing laws and regulations
	- Lack of data on impacts.		- Organization of farms (within this subsystem; between this subsystem and the following; with actors of other supply chains)	
Agro-industrial	- Adoption of circular processing technologies and practices;	-Adoption of circular business models	- Entrepreneurs' willingness to participate to CE trajectories;	- Obstructing laws and regulations
	- Lack of data on impacts.		- Organization of supply chain (within this subsystem; between this subsystem and the following; with actors of other supply chains)	
Consumption		- Consumers' interest, acceptance and participation		

Source: adapted from Borrello et al., 2016 and Kirchherr et al., 2018.

2019b), their habits are far from being changed. As for this barrier, CE entails a more participative consumer (Borrello et al., 2017; Camacho-Otero et al., 2018) willing to be engaged and to support circular supply chains through his preferences.

- Coordination: CE entails cooperation among firms for the exchange of biological materials. Thereby, new organizational arrangements and specifically designed contracts must create incentives for participation to CE, integrating and coordinating actors in the process of exchange materials, realize common investments, and coordinate activities (Raimondo et al., 2018; Giannoccaro et al., 2019a). However, one of the most pressing barriers for CE is finding farmers and entrepreneurs keen to participate in CE trajectories not only by adopting novel technologies, but also by adapting their business models and organizational structures (Zhu et al., 2011).
- Regulatory: CE strategies may also conflict with the established regulative framework (Hartley et al., 2020). To illustrate, Italian legislation imposes the invol-

vement of intermediate companies for the pre-treatment of wastes and by-products, thus decreasing the economic efficiency of circular interactions (Simboli et al., 2015). Another example is one of organic production standards that in some cases conflict with the farm adoption of recycled materials (Løes and Adler, 2019).

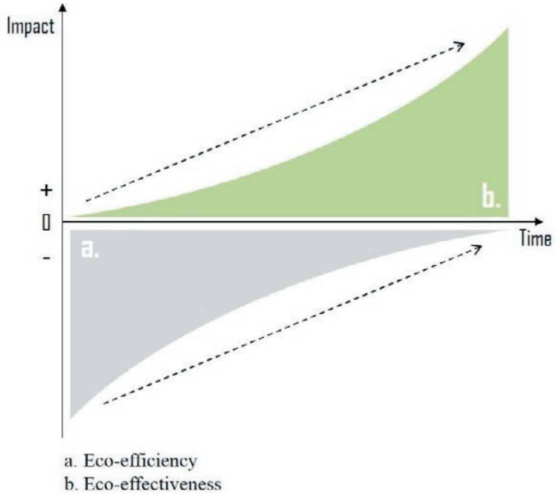
3.2 *Envisioning and Exploring trajectories*

Exploring how a system can evolve from the current situation (envisioning) and exploring how trajectories can be translated into practical action are the second and third steps of the MLP guiding framework. The current paper considers these two steps together since envisioning a system and looking at (experimenting) the trend-breaks required for a transition are meant to be an outcome of a

Table 3. Agri-food supply chain challenges and issue per subsystem.

		Technological	Market	Coordination	Regulatory
Agro-ecological subsystem	Issue	Product-specialized farms and strong territorial specialization	Smallholders farms	Weak cooperative setting	Linear model regulation
	Challenge	Innovate to regenerative farming practices and byproduct valorization	Innovate to Circular Business Models	Participate to circular interactions by cooperating with other farmers and along the supply chain	Setting regulation facilitating the exchange of farms/ firms biological materials
Agro-industrial subsystem	Issue	Highly specialized technology	Smallholders firms	Weak vertical integration	Linear model regulation
	Challenge	Supply of wastes and by-products to downstream industries Adoption of novel recycling technologies	Transition to sustainable (circular) business models	Participate to circular interactions by cooperating with farmers and downstream industries	Setting regulation facilitating the exchange of biological materials
Consumption	Issue		Linear pattern of consumption		
	Challenge		Commitment to support circular supply chains through consumers' preferences		

Figure 3. Eco-efficiency vs. eco-effectiveness.



Source: Borrello et al. (2020a), adapted from Braungart et al. (2007).

process where technical solutions are taken under consideration and innovation trajectories are defined. It is out of the scope of the current paper providing the latter in detail. However, some suggestions on how to proceed are provided. Starting from the list of challenges, the *status quo* of each subsystem has to be compared with alternative trajectories based on CE principles and has to be assessed to choose among different alternatives (Fig. 3).

Issues reported condition the choice of trajectories that can be translated into practical actions. Each subsystem needs to be studied through a specific approach keeping in mind the *eco-effectiveness* of the whole system. Eco-effectiveness is a pillar of CE. To briefly describe eco-effectiveness, we start from the well-known concept of eco-efficiency. Eco-efficiency is a way to improve economic performance by reducing environmental impacts (Dyllick and Hockerts, 2002). Although reducing the use of energy, water, and resource inputs, as well as waste and pollutants, are welcome, these strategies keep on taking for granted linear material flows (Braungart et al., 2007). Eco-effectiveness goal, on the contrary, "is not to minimize the cradle-to-grave flow of materials, but to generate cyclical, cradle-to-cradle 'metabolisms' that enable materials to maintain their status as resources" (EMF, 2012, p.23). Therefore, whereas eco-efficiency strategies seek to reduce negative effects ("doing things right"), eco-effectiveness is based on envisioning new ways to produce materials, design products, and structure industrial systems and business models ("doing the right things") (Herrmann et al., 2015). Put differently, eco-efficiency approaches sustainability starting from negative environmental effects, with the final goal of striving for zero impacts. On the contrary, based on novel design, eco-effective innovations are ideally conceived to have zero impact from the beginning and to produce positive effects over time (Fig. 3).

The design of circular eco-effective products can be achieved by applying the concept of upcycling. Singh and colleagues (2019) define upcycling as "a process in which products and materials that are no longer in use, or are about to be disposed, are instead repurposed, repaired, upgraded, and remanufactured in a way that increases their value". Upcycling is meant, then, as a strategy that offers many subsequent lives to material objects, also with completely different functionalities (Bridgens et al., 2018). Contrariwise, the common recycling concept entails that recycled products or materials have a lower value than those they come from (Borrello et al., 2020a).

3.3 Experimenting

The experimenting step is crucial to explore how the chosen trajectories can be translated into practical operational activities. The current paper suggests a list, though not exhaustive, of possible empirical methodologies to address the mentioned challenges per each subsystem of agri-food supply chains.

3.3.1 Agro-ecological and agro-industrial subsystems

Most of current agri-food supply chains have to face four challenges (technological, market, coordination, regulatory) related to cultivation and harvesting, as well as to food processing. The ultimate objective is to trigger the adoption among farmers (especially smallholders) and entrepreneurs of circular technologies, business models, coordination strategies and to eliminate obstructing regulations for the adoption of CE trajectories.

A relevant decision to make is the geographic extension of the supply chain, namely the boundaries of the system at hand. An agri-food supply chain can be local, regional, composed of macro-areas, national or international, considering a path going from the location of providers to that of costumers. The criterion to identify the system boundaries depends on a trade-off among different factors, such as the need to have a thorough supply chain analysis, the need to simplify complexity, availability of data and relevance of the network elements for the supply chain at hand. Once decided how far the supply chain goes, it would be necessary to analyze current linear practices to have a comprehensive overview of farming/entrepreneurial practices with respect to farm/firm structure. Starting from this, alternative CE trajectories (*e.g.*, regenerative agriculture models, upcycling of by-products) can be selected. A methodological approach could be structured in three stages: i) data collection of official statistics regarding the structure and organization of the agri-food chain at hand in the target area/s; ii) identification and characterization of the most representative farm/firm typologies based on official statistics elaboration; iii) interviews with technical experts to gather information on current linear farming/entrepreneurial practices and technologies and the available alternative CE trajectories.

The market is also important. Its knowledge is relevant to generate guidelines for the most appropriate Circular Business Models (CBMs) to promote the adoption of CE trajectories at farm/firm level. A possible empirical strategy could be made of the following subsequent steps: i) mapping current factors constraining the transition towards CBMs through causal loop diagrams; ii) connecting technical solutions to the problems: coordinating the development of maps linking the constraining factors; and iii) connecting technical solutions to the actors: analysing the innovative ecosystems around the technical solutions introduced in the selected case.

A study concerning coordination is needed. It should focus on the attitude of farmers and entrepreneurs towards CE and on organizational elements. On the one hand, the study of coordination might examine stakeholders' perception of lock-ins to participate in CE by using semi-quantitative methods, combining a structured survey and experimental economics games like public good games or trust games. A Best-Worst Scaling (BWS) analysis would allow to rank circular trajectories on the base of readiness to be implemented, selecting market-driven incentives to enhance implementation. To assess stakeholders' willingness to adopt circular solutions, a survey could be submitted for getting information on farmers' stated preferences for technological, organizational, managerial items, under specific market incentives and regulatory frameworks. On the other hand, the organisational drivers towards agri-food management practices based on closed loops of nutrients, shared resources and diversified agro-ecological systems should be evaluated. It could be done by i) mapping potential circular agri-food systems; ii) identifying and analysing organisational drivers of resource efficiency, restoration and resilience in circular systems; and iii) using results obtained, it could be possible to co-create with stakeholders an interactive and online Circular Tool Kit (CTK) to identify key strategic issues related to the different trajectories.

A specific study on regulation is of paramount importance. A focus should be done on the identification of relevant attributes of potential public policies and laws that may foster the transition to CE trajectories. A possible empirical strategy could be analyzing the demand of policies and laws starting from the needs of practitioners in the sector. In order to design guidelines for a potential implementation of policy interventions able to encourage the development of CE trajectories, experimental works could be carried out implementing the Delphi method. Based on subsequent rounds in which experts are asked to provide their opinion on a certain issue, the Delphi method has already had wide adoption in agri-food research. For example, it has been used to develop food safety indicators and analyze food safety governance (Camanzi et al., 2019; Di et al., 2021), to design food label contents such as health claims (Hung et al. 2019) and to identify most relevant plant breeding techniques for future food security (Lassoued et al., 2018). The expected results would be the identification of regulatory, administrative and institutional factors, relevant for promoting the adoption of CE trajectories.

3.3.2 Consumption subsystem

In this subsystem, the aim would be to assess consumers' willingness to participate in CE models by buying food produced through CE initiatives. CE creates value by lending products extrinsic attributes related to the creation of resilient agri-food systems (Camacho-Otero et al., 2018; Borrello et al., 2017, 2020a; Giannoccaro et al., 2019b). Therefore, addressing one way to address consumers' issues consists in finding the conditions in which consumers can capture this value and support, through their purchase behaviour, companies engaged in CE. Specific research activities can cover different aspects. Here we suggest some that might be the following. A national representative sample of households to identify: a) consumer perceptions, expectations and preferences for food products with sustainable attributes; b) the most preferred products/attributes/innovations combinations; c) the most attractive segments of the market (targets) (Caracciolo et al., 2016; Giannoccaro et al., 2019b; Henchion et al., 2019; Staples et al., 2020). As for research designs, data could be gathered by means of choice-based conjoint models and analysis performed by means of statistical and econometric models (Anabtawi et al., 2020; Rizzo et al., 2020b). Also, non-hypothetical, incentive compatible (participants have real economic incentives to reveal their preferences, truthfully avoiding the hypothetical bias problem) framed field economic experiments could be implemented. More specifically, they could be useful to analyse consumer perceptions, expectations, and preferences for the selected attributes stemming from the national survey results. Among incentive compatible methods, BDM (Becker-DeGroot-Marschak) (Migliore et al., 2018; Riefler, 2020) and/or Random Nth price/Multiple price list methods (Strzok and Huffman, 2015; Jin et al., 2017; Lombardi et al., 2019; Rizzo et al., 2020a) might be implemented to elicit willingness to pay for innovative circular attributes. Non-hypothetical natural field economic experiments could also be performed in real food shopping environments (supermarkets, general and speciality stores), in targeted locations, to verify consumer preferences for the selected products, under different information treatments and with a control condition (Vecchio et al., 2016; Menapace and Raffaelli, 2017). Non-hypothetical real choice experiments with information treatment might be implemented and Structural Equation Modelling (SEM) procedure applied on data gathered (Voon et al., 2011; Vecchio et al., 2016; Boobalan et al., 2021).

3.4 Assessing

The assessing step of this transition management approach is aimed to monitor the effectiveness of CE trajectories. This is part of a reflection and learning process aimed to identify best strategies and tune the elements of circular solutions. To this aim, Life Cycle (LC) approaches are useful to supervise impacts. We propose that the assessment step considers all three sustainability dimensions (environmental, economic and social) by implementing LC approaches at the agro-ecological and agro-industrial subsystems taken as a whole (De Luca et al., 2018). The objective would be to compare the observed linear production processes, with the alternative closed-loop trajectories identified in the previous steps, also in order to verify which are beneficial in environmental, social and economic terms (Fusco Girard and Nocca, 2017; Noya et al., 2017). Through LC protocols, it is possible to test environmental, economic and social performances of CE solutions, validating assumptions and generating feedback for improvement. A Life Cycle Sustainability Assessment (LCSA) is able to conclude the analysis by combining the three differentiated tasks: Life Cycle Assessment (LCA), environmental and conventional Life Cycle Costing (LCC), and Social Life Cycle Assessment (sLCA). These three methodologies have already found wide implementation in studies analyzing the impacts of the agri-food industry (see, for example, Roy et al., 2009 and Omolayo et al., 2021 for the LCA; Mohamad et al., 2014 and Peña and Rovira-Val, 2020 for the LCC; Prasara-A and Gheewala, 2019 and Sureau and Lohest, 2019 for the sLCA).

LCA is an environmental impact assessment methodology used to characterize and quantify the impacts in terms of specific mid-point indicators (e.g., Global Warming, Human Toxicity, Ecotoxicity, Water Depletion Potential) and/or end-point indicators (Human health, Ecosystem, Resources).

The economic impact assessment can be performed by using the LCC to analyze and evaluate the overall economic performances, identifying bottlenecks in adopting selected CE trajectories. LCC is a tool able to identify and quantify the main cost items, but also financial indicators of investment, throughout the life cycle stages, by classifying them in terms of initial costs, periodical maintenance costs, operational costs, and end of life disposal costs or residual value. In addition, eLCC (environmental Life Cycle Costing) can provide all costs associated directly covered by one, or more, of the actors involved in the products life cycle, including externalities that are anticipated to be internalized in the decision-relevant future.

Last, but not least, sLCA can be carried out to study whether the social performances (in terms of impact categories as, for example, working conditions, fair wage, psychosocial risk factors, etc.) of the CE trajectories identified (e.g., valorization of by-products) can be considered as significant improvements compared to conventional scenarios of production.

3.5 Translating

The last step of the analytical framework concerns the translation of insight emerged throughout former steps into actions able to actually stimulate circular trajectories. In this phase, the action of political actors is of paramount importance. Their actions should be aimed to support the implementation of CE trajectories and remove the barriers that prevent the adoption of circular solutions. On the one hand, policy makers are expected to provide financial support for researchers and practitioners directed to the implementation of the identified trajectories that have the best performances according to life cycle protocols. This support should be aimed to identify tailored case-specific solutions to address lock-ins related to the trajectories. By adopting participative and dynamic co-creation processes, this would provide farms/firms with a resilient structure able to face the challenges occurring during the transition. On the other hand, regulative barriers should be removed allowing the implementation of circular solutions. As for this, a process of harmonization of different regulations in order to assist CE not disregarding other pursued goals is necessary (e.g., considering waste management and organic farming practices, Simboli et al., 2015, Løes and Adler, 2019).

Even though the translation process cannot leave out of consideration public intervention, individual behavior of private actors is also crucial. Public intervention can provide incentives to private actors, but transitioning to CE requires a profound cultural modification. Even though it has remained implicit among the transition challenges considered in this paper, culture cannot be disregarded. Kirchherr and colleagues (2018) consider culture one of the most pressing barriers for CE, in terms, for instance of "hesitant company culture" and "lacking consumer awareness and interest". These criticisms might be expected to be reverted in the transition process by public intervention. However, at the macrolevel, Geels (2019, p. 190) considers "cultural repertoires" and "societal concerns" as landscape elements; furthermore, in his theoretical model, new socio-technical systems have a feedback impact on the landscape. By this logic, one could expect that future translating processes will include among its mechanisms a reciprocal influence of, on one side, novel and dynamic circular system configurations, and on the other side, cultural inclination of individual actors to engage in CE.

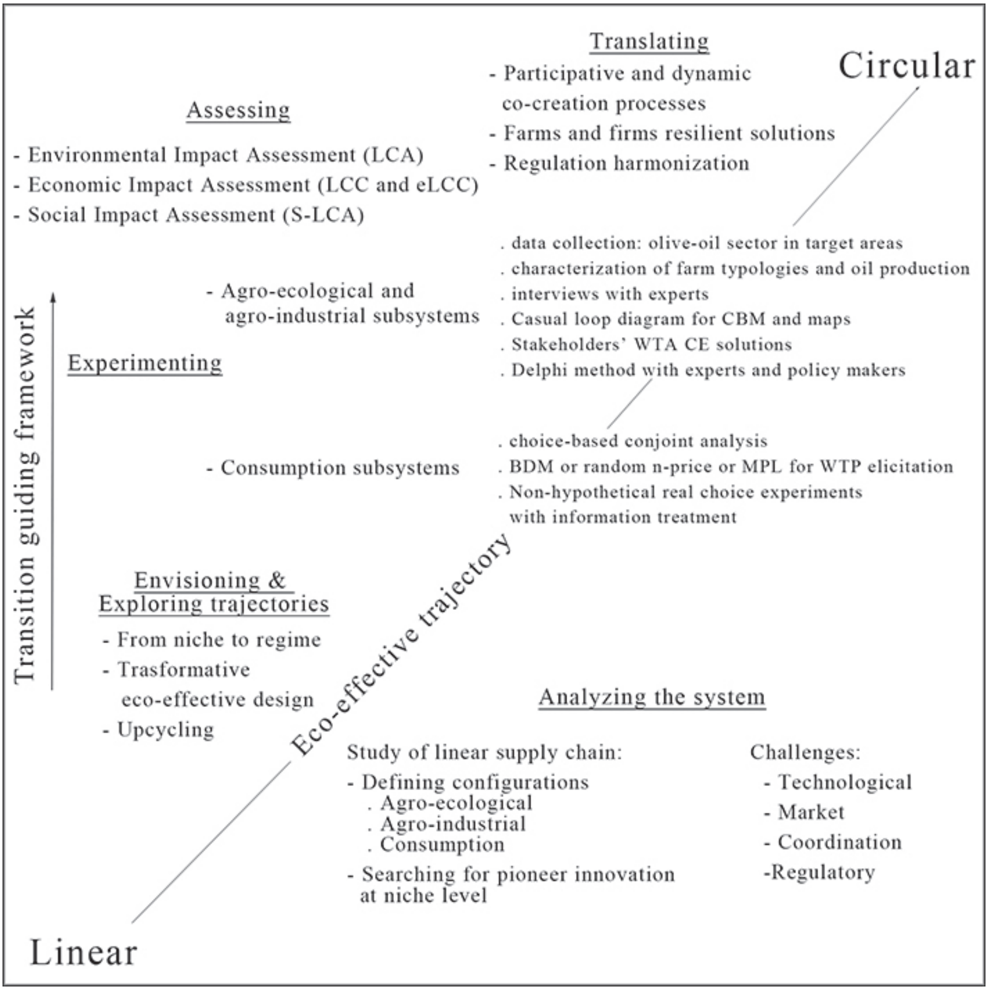
4. Conclusions

Grounded on the theory of socio-technical transitions, the current paper has suggested an analytical framework to identify suitable solutions for transitioning into agri-food circular economy trajectories.

One of the imperative issues that contemporary societies are facing is finding long-term solutions to recreate a balanced co-existence of ecological and economic systems. Circular Economy might provide in the coming decades the key paradigm to re-think the way we make things. Starting from the observation of the perpetual cycle of the elements within natural ecosystems, CE theorists suggest that future industries will have to adopt a restorative design to survive in a world where current exploitation rates of natural resources will be unacceptable. This might be particularly true for agri-food productions, where implementing CE would essentially consist in finding solutions to make value chains complying with biological metabolisms. This should be done by identifying integrated strategies considering the three blocks of industrial agri-food supply chains, namely primary production (agro-ecological subsystem), commercial food production (agro-industrial subsystem) and consumption.

To seek that circular agri-food systems will not remain a utopia, scholars are called to begin by applying and make operational the key elements of transition theory. A transition approach considers extant supply chains the arena on which building CE trajectories, by addressing the most critical challenges (technological, market, coordination, regulatory). Following this logic the current paper has suggested an analytical framework for effective transition management with two main objectives: i) study how to foster and manage the transition of agri-food

Figure. 4. Flowchart representation of the MLP guiding framework.



chains into a CE model; and ii) evaluate the impacts of different agri-food transition trajectories to CE.

We are aware that the range of approaches and methodologies is much wider than the one presented in the current paper. However, we believe that what is presented in this manuscript gives a systematic idea of a feasible analytical framework to implement and guide the transition of agri-food systems into CE (Fig. 4).

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Urban Ecosystem Services to support the design process in urban environment. A case study of the Municipality of Milan

In dense urban areas nature capital is a vital resource for providing numerous ecosystem services important for human welfare and survival but at the same time cities provide several different private and public services. Both, natural and human services, contribute to the overall well being of the citizens. The present paper aims at mapping and evaluating the "Urban ecosystem services" (UESs) that are generated from natural capital in combination with human-derived capital, and that contribute, directly or indirectly, to human well-being in urban areas. This paper aims at analysing, mapping and evaluating different types of UESs both natural and human origin in the case study of the municipality of Milan. A Multi-Criteria Decision Analysis (MCDA) approach has been implemented to synthetize and map the UESs. Finally, the paper describes how the present approach can support the design and urban planning process.

1. Introduction

Nature capital is a vital resource for providing numerous Ecosystem Services (ESs) important for human welfare and survival (Costanza et al., 1997), mainly in urban areas where human activities undermine urban ecosystems but reduce ecosystem functions and capacities to provide services (Kreuter et al., 2001), due to environmental deterioration and landscape fragmentation (Englund, et al., 2017). Moreover, cities contribute to the overall well-being of the citizens by providing several different private and public services. The mapping and evaluation of the ESs in urban areas should consider and account for both natural and artificial services.

In the Biodiversity Strategy for 2030, the European Commission has stressed the role of the ESs in the protection of biodiversity both in natural and anthropized environments, and the need for their comprehensive mapping, monitoring or assessing, to enhance the knowledge and awareness and to ensure the EU's resilience, climate change mitigation and adaptation (European Commission, 2020).

One of the most accepted definition of ESs describes them as the value humans obtain, whether social, economic or ecological, from natural ecosystems (both wild and managed) and the flora and fauna species they comprise (Alcamo and Bennett, 2003). Moreover, they are commonly categorized into four groups including supporting services (e.g., biodiversity and habitat), provisioning services (e.g., food and water), regulating services (e.g., temperature regulation, noise re-

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duction, and air purification) and cultural services (e.g., recreation, aesthetics and cognitive development) (Croci et al., 2021).

ES knowledge can generate actions by supporting the formulation and structuring of the decision problem and the identification of criteria for screening, ranking and spatial-targeting of the alternatives (Cortinovis and Geneletti, 2018).

Urban society is disconnected and independent from ecosystems, but demand for ecosystem services is increasing because citizens are aware of their crucial role in reconnecting cities to the biosphere, restoring local commons, reducing ecological footprints, orchestrating disciplinary fields and stakeholder perspectives, guiding policies to improve quality of life and, finally, guaranteeing long-term conditions for life, health, good social relations and other important aspects of human well-being (Gómez-Baggethun et al., 2013).

Cities seek to increase the amount and quality of green space to ensure benefits to different groups of citizens (Cortinovis and Geneletti, 2018) and the study of ESs in urban environment is emerging as an important research frontier for the incorporation of these benefits in the urban context (Kremer et al., 2016).

The inclusion of ESs knowledge in urban spatial planning processes can contribute to highlight existing needs, to define standards and policy targets, to design implementation tools, to support the selection and fine-tuning of alternatives (Cortinovis and Geneletti, 2018).

"Urban ecosystem service" (UESs) defined as "aspects of ecosystems that are generated from natural capital in combination with human-derived capital, and that contribute, directly or indirectly, to human well-being in urban areas" (Tan et al., 2020), are an innovative concept to describe and measure ESs in urban environment and shape urban landscapes to be more sustainable and liveable (Haase et al., 2014; Luederitz et al., 2015). They refer to a very wide range of benefits provided mainly by a diverse range of urban elements covering natural ecosystems, constructed ecosystems, and to a limited extent, the abiotic components of cities. In fact, as ESs highlight human dependence on natural ecosystems, UESs reinforce the idea that ecosystems services can be locally produced in urban areas to support human well-being in tangible and intangible ways. UESs encompass both ESs belonging to the natural environment and a wide range of services produced by humans, including housing, transport, education, entertainment, or medical care. So, although urbanization leads to a general dissociation of urban dwellers from nature (Turner et al., 2004), UESs provide opportunities for urban dwellers to experience nature (Andersson et al., 2015) and acts as a social tool to bring together diverse stakeholders to foster community driven (Luederitz et al., 2015) and government-led planning (Rall et al., 2015) for urban sustainability.

More than in rural and natural areas, in the urban context the balance and competition between natural and human capital is a relevant factor for the economic development and the liveability. The UESs can support the comprehension and measurement of the trade-off between increased provision of human services triggered by a management choice (Verhagen et al., 2018) and/or human intervention and the reduced provision of natural ones (Deng et al., 2016; Haase et al., 2012; Rodríguez et al., 2006). The knowledge of trade-offs may support decision-making and policy instrument design (Verhagen et al., 2018) up to European scale (Ruijs et al., 2013), by avoiding the loss of important UESs and promoting synergies between different UES (Burkhard et al., 2014; Carreno et al., 2012).

As, different types of UESs are produced depending on which scale is applied, and which boundaries are used to define the ecosystem of interest, mapping them is essential because can allow full assessment and quantification of UESs (Crossman et al., 2013, Yang et al., 2019), including the spatial distance between providing areas and benefiting areas (Fisher et al., 2009; Bastian et al., 2012). Mapping can be also crucial for the evaluation of the benefits of the UES (Sylla et al., 2020). Both monetary and non-monetary methods have been applied to assess the value of ecosystems in decision-making. Multi-Criteria Decision Analysis (MCDA) is suited for integrated valuation of ecosystem services because it can combine information about the performance of the alternatives with respect to evaluation criteria with subjective judgments about the relative importance of the criteria in a particular decision-making context (Vatn, 2009).The present paper aims at analysing, mapping, and evaluating different types of UESs both of natural and human origin in the case study of the municipality of Milan, by applying the methodology developed by Burkhard et al. (2009; 2012; 2014). A MCDA approach has been implemented to synthetize and map the UESs, combine objective and subjective assessments (ref.), and support the Decision-Maker (DM) in designing the most suitable solution among a set of alternatives (Roy, 1985; 2005).

MCDA allows multiple sources of information and value dimensions to be combined, to address UES-related issues within the urban planning framework and offers a structured way and balance diverse and sometimes competing interests (Cortinovis and Geneletti, 2018). Moreover, combining MCDA and UES approach improves the urban planning tools and aids decision-making to maximize multiple ESs benefits to increase human wellbeing in cities (Kremer et al., 2016).

Our study comes on top of other recent papers which have studied the contribution to UES to the sustainability and planning in European and non-European cities. In particular, Gómez-Baggethun et al., (2013) recognized the provision of water supply, flood mitigation, coastal zone protection and tourism as important UES to the City of Cape Town and described programs and projects aimed at attempting to restore these and thereby enhance ESs benefits.

A study on New York City stressed the role of UES in city planning, to better understand trade-offs and synergies and to generate best practices for managing and enhancing biodiversity and ecosystem services in the New York metropolitan region (Gómez-Baggethun et al., 2013). A second one, again on New York City, identifies patterns of distribution and access to UES important for understanding inequity issues with respect to UES benefits and for informing holistic decision-making regarding conservation priorities (Kremer et al., 2016).

A recent research on the City of Toronto highlighted the importance of scale, referring specifically to data resolution (i.e., the granularity of data) and measurement scale, which relates to the number of enumeration units (or census levels). The main output of the paper is the recognition of how specific land use and land cover properties act as representatives of ecosystem processes (Emily C. Hazell, 2020).

Li et al. (2020) have implemented a multi-criteria approach integrating ecological and cultural services evaluation to obtain a more comprehensive assessment of the demand for UES in Beijing. Their results show that some small green spaces located in densely built-up areas have a higher demand for ESs than that of large green spaces, so that the consumption of cultural services is closely related to the distribution of green space and the composition of surrounding residents (Li et al., 2020).

Another interesting study focused on the provision of cultural ESs in Barcelona is also crucial in urban parks, and demonstrated that the limited amount of green space in the dense city requires a broader acknowledgement of citizens' needs in the planning of urban green spaces and brown-fields have a high potential to provide ESs (Gómez-Baggethun et al., 2013).

The presence of brownfields and abandoned areas are at the core of the paper of Cortinovis and Geneletti on the city of Trento, where the expected benefits in terms of improved cooling effect by vegetation and enhanced opportunities for nature-based recreation have been studied to address two of the most critical issues for citizens' well-being in Trento (Cortinovis and Geneletti, 2018).

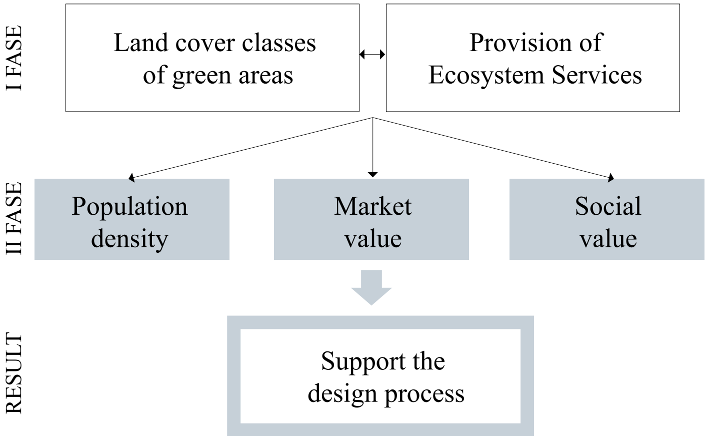
Finally, Cerreta et al. (2020) applied a 3D virtual model to visualize UES trade-offs simultaneously, in order to identify opportunities linked to a sustainable spatial policy, and to implement a multi-scale decision-making process (Cerreta et al., 2020).

Although our results are targeted to the urban planning of the City of Milan, the study framework is repeatable and can be applied to any other study areas if suitable indicators and weights are adopted. The remainder of this paper is organized as follows. The second section presents the methodological framework. The third section describes the case study. The fourth section details the application, articulated in two phases. The fifth section presents and discusses the results both the descriptive statistics and the aggregation. The sixth outlines how the approach can support the design process. A general conclusion ends the paper.

2. Methodological framework

Since benefits produced by the presence of green areas are becoming an evidence given by their positive effects on the wellbeing of the population, the climate change regulation, and the maintenance of biodiversity (Camps-Calvet et al., 2015; Miller and Montalto, 2019), it is strategic to support their design. Moreover, the provision of ESs is directly related to the land use and to the characteristics of the context under analysis. In order to take into consideration both intrinsic and extrinsic features, the methodology proposed within this research combines the evaluation of ESs according to the model developed by Burkhard et al. (2009; 2012; 2014) with the analysis of the population density, the market value and the social value, to result with a critical reading of the current state of the context, aimed at supporting the design process. The approach is based and takes advantage by the support of the MCDA and the generation of maps through the use

Figure 1. Methodological framework.



of Geographic Information Systems (GIS) software which gives the possibility to directly visualize on the territory the results of the investigation. MCDA methodologies aid the DM in structuring the problem and in defining the most suitable solution among a set of alternatives (Roy, 1985; 2005), while GIS allows to elaborate and manipulate a large number of spatial data and information under a georeferenced environment (Dell'Ovo et al., 2020). The application of MCDA methodologies within the GIS environment, implements the potentialities of the decision-making process by improving the transparency of the process and the awareness about the problem (Dell'Ovo et al., 2020).

The analytical phase has been developed in different phases (Figure 1); while the first two are aimed at critical reading the state of the art and the existing characteristics of the territory under analysis, the third one has as main objective the elaboration of data collected in order to support the design process.

- The objective of the first phase is the quantification of ESs according to the land use types. The process has been developed by assuming the values elaborated by Burkhard et al. (2009) and Zhang and Ramírez (2019) within their studies. The method considers the land cover classes included in the CORINE program of European Union and assigns a qualitative/numerical valuation (where 0 is the lowest value and 5 the highest) considering their provision of ESs. As described by Burkhard et al. (2009; 2012; 2014), values have been assessed by first expert evaluations and then based on experience from different case studies. Experts were asked to express their judgement considering the classification of ESs provided by Millennium Ecosystem Assessment (MEA, 2005) and grouped in four categories: supporting services, provisioning services, regulating services and cultural services. The result of the first phase is the visualization of both partial and overall outcomes of the judgments obtained by associating the values carried by the different land uses present in the context under analysis.

- The second phase is aimed at analyzing characteristics of the territorial context and in correlating them with the outcomes obtained in the previous step. By understanding demands, criticalities and strengths of the territory, it is possible to give a specific and contextualized support to planners, architects and policy makers to guide the design process. The process has been developed by involving significant features able to influence the social and economic condition of an area and to provide a picture of the current state. The result of this phase consists in a deep investigation of the following aspects:
    - Population density: allows to understand how many people are positively influenced by the presence of the green areas and could receive beneficial impacts by the provision of ESs;
    - Market value: allows to understand if the market values of residential assets are affected by the presence of green areas and their provision of ESs;
    - Social value: allows to understand the provision of services by considering the presence of health facilities, public transport stops and schools in order to better understand the quality of the urban spaces (Oppio et al., 2018).
- Once these two phases of analysis have been developed and data have been elaborated, the goal of the third and last phase consists in providing operational recommendations to guide new design actions according to their level of priority by critically reading the results obtained through a deep understanding of the context and considering both strengths and criticalities.

3. Case study

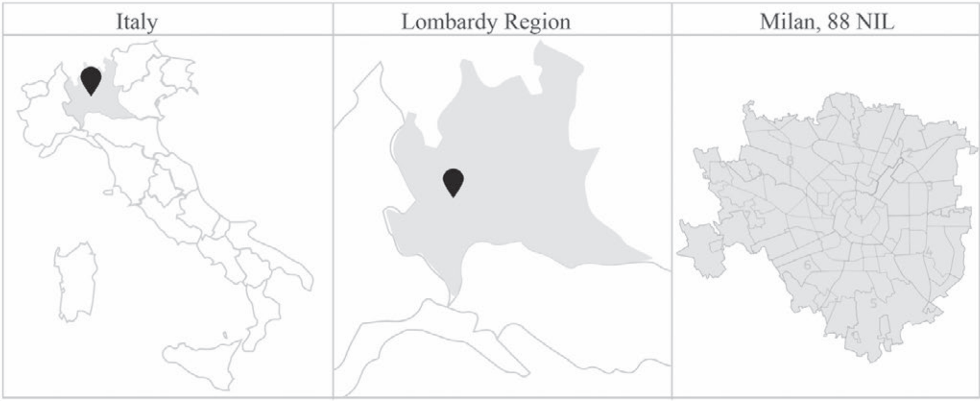
The case study selected to apply the methodological framework previously described is the municipality of Milan, located in the northern part of Italy. Milan has a population of about 3 million people (ISTAT, 2019) and is characterized by a high level of urbanization and, consequently, by a high level of soil sealing. Milan has been affected in recent years by an exponential growth in population with its economic development, in fact its attractiveness is directly related to its inclusion in circuits of the flow economies and high finance (Dicken, 2003; Sassen 2018; 2001; Sdino et al., 2020).

Currently the city is represented by a fragmented belt of agricultural fields still productive, located at the edges and recently (Sanesi et al., 2017) the local Administration is developing new green policies by proposing and supporting sustainable projects. In fact, one of the main objectives of the land management plan 2030 consists in a green city, liveable and resilient to achieve by reducing the soil consumption, designing new parks and green roofs.

Nowadays the metropolitan area is characterized, for administration purpose, by 9 main areas, further divided in 88 local identity centres (Nuclei d'Identità Locale - NIL) (Figure 2).

This smaller division is the one used in this study to map and evaluate the ESs. The small dimension of each NIL allows to detect detailed and punctual information and to give the possibility to observe potential interactions and the perception of the population.

Figure 2. Location of the Municipality of Milan and division in 88 NIL.



Once the case study has been limited and identified, the next phase consisted in mapping and classifying green areas in seven categories, namely: Agricultural areas; Garden; Uncultivated; Vegetable garden; Public park; Traffic island; Highway-infrastructure green (Table 1).

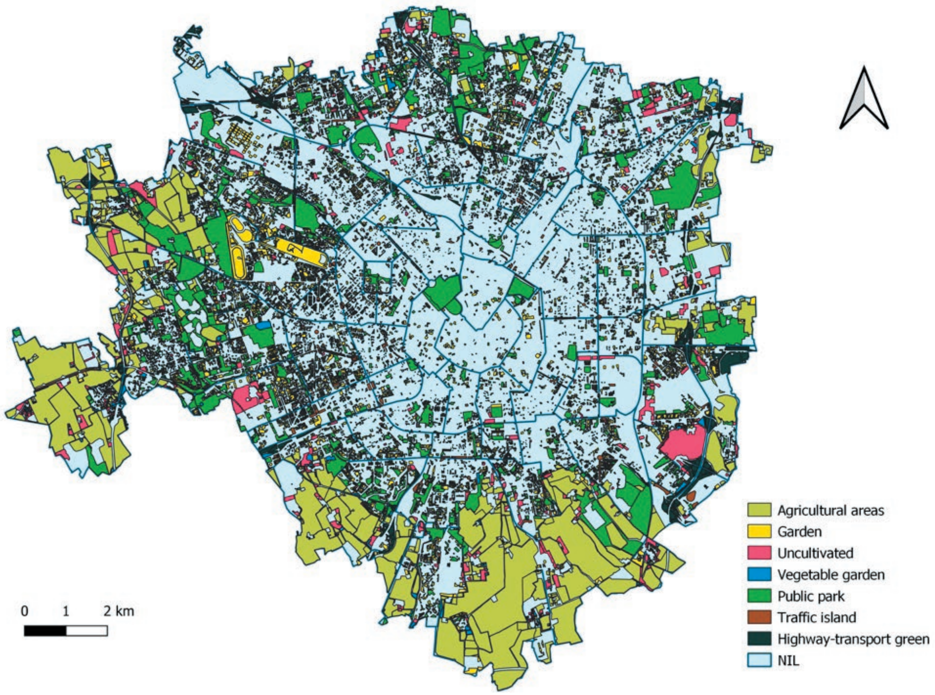
This classification has been applied to analyze each NIL presents in the Municipality of Milan and data regarding classes previously defined have been detected from Google satellite image and elaborated with QGIS since open data available where not sufficient for the analysis and the classification. The collection of data has been carried on by observation and some errors should be taken into consideration given the accuracy of the green area's representation identified. Figure 3 presents the results of the green areas classification by considering the seven categories.

As it is possible to observe from the map, agricultural areas are mainly located in the periphery, and more in detail on the southern and western side of the city

Table 1. Green areas classification.

Categories	Description
1. Agricultural area	Agricultural areas and agricultural production zones
2. Garden	Private green areas
3. Uncultivated	Abandoned areas and uncultivated areas with spontaneous vegetation
4. Vegetable garden	Private or community garden
5. Public park	Public green areas, public parks, and playground
6. Traffic island	Green areas at the border of avenues or large crossings
7. Highway - infrastructure green	Green areas at the border of highways and railways or close to airport areas

Figure 3. Green areas mapping.



while public park, garden and uncultivated areas are present, even if with different dimensions, in all the territory.

4. Application

4.1 First phase

Once data regarding green areas in each NIL of the Municipality of Milan have been detected, it has been possible to proceed with the application of the methodology previously defined. In detail in the first phase, the model developed by Burkhard et al. (2009; 2012; 2014) and Zhang and Ramírez (2019) has been applied considering the values proposed by their researches for each category mapped. As it has been already mentioned in the second section, values assigned to the different land uses have been assessed by first expert evaluations and then based on experience from different case studies. This methodology is based on the concept that different land uses, and within this context different green areas, can provide different levels and typologies of ESs. Their provision has been calculated considering several projects on different scale and eliciting the opinion of experts (Burkhard et al., 2012). In order to result with a final performance of provision of

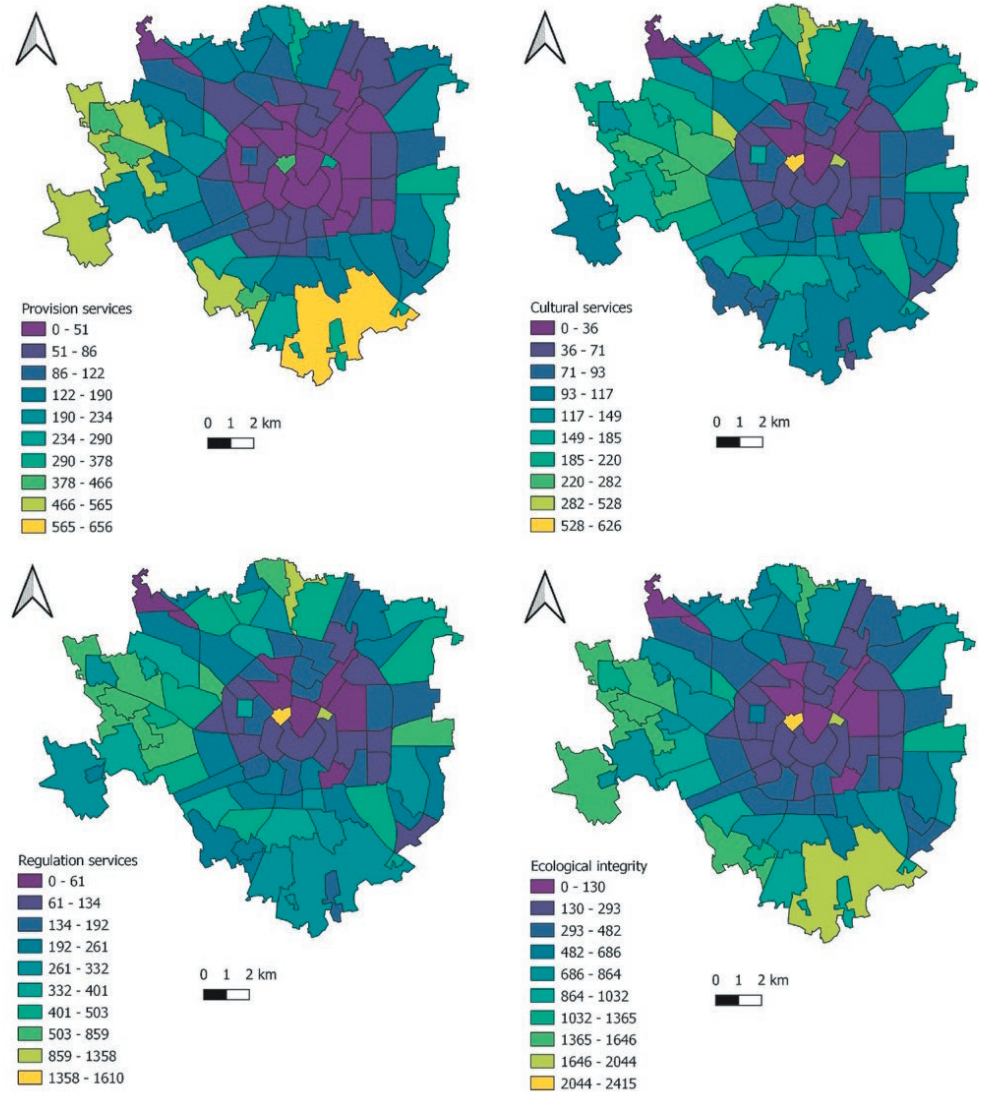
Table 2. Matrix for the assessment of the different green areas.

	Agricul-tural area	Garden	Unculti-vated	Vegetable garden	Public park	Traffic island	Highway - infra-structure green
Provision services	**8**	**5**	**3**	**5**	**5**	**1**	**1**
food	5	0	0	3	0	0	0
genetic resource	2	1	3	2	2	1	1
ornamental resources	1	4	0	0	3	0	0
Cultural services	**1**	**7**	**0**	**1**	**7**	**1**	**1**
aesthetic	1	3	0	0	3	1	1
recreation	0	4	0	1	4	0	0
Regulation services	**3**	**10**	**6**	**0**	**18**	**3**	**0**
local climate regulation	2	3	2	0	5	1	0
global climate regulation	1	2	1	0	4	1	0
air quality regulation	0	2	1	0	4	1	0
nutrient regulation	0	1	1	0	1	0	0
erosion protection	0	2	1	0	4	0	0
Ecological integrity	**21**	**18**	**17**	**15**	**27**	**6**	**4**
abiotic heterogeneity	3	3	2	2	3	2	2
biodiversity	2	3	3	2	4	2	2
biotic water flows	3	2	2	2	4	0	0
metabolic efficiency	3	1	1	2	3	0	0
exergy capture (radiation)	5	4	4	4	5	0	0
reduction of nutrient loss	1	3	3	1	3	1	0
storage capacity (SOM)	4	2	2	2	5	1	0
ES tot	**33**	**40**	**26**	**21**	**57**	**11**	**6**

ESs for the different NIL, all the green elements present have been scored considering the values illustrated in Table 2 and summed together. Values have been elicited by considering the four classes of ESs further divided according to the definition provided by MEA (2005).

The mapping of green areas, together with the value assignment for the different classes, allowed to understand for each NIL the partial provision of ESs considering the four categories (supporting services, provisioning services, regulating services and cultural services) (Figure 4) and the overall provision of ESs (Figure 5). Synthetizing the process, the green areas have been detected and weighted considering their cover percent on the NIL. The final value has been cal-

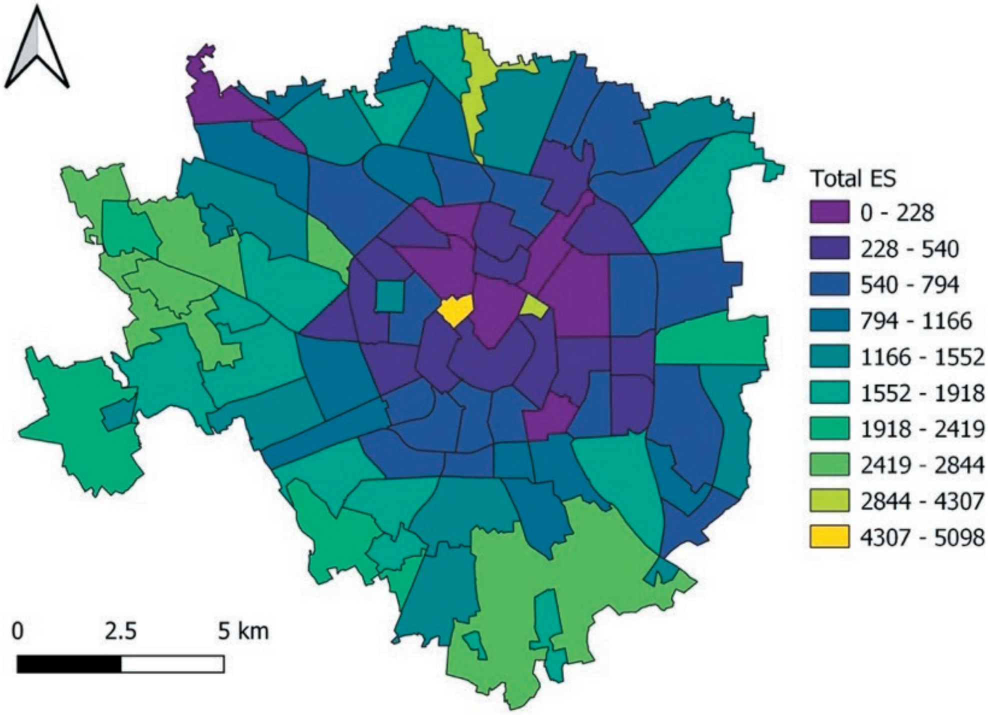
Figure 4. ESs provisions according to the four categories.



culated by summing up the results of the multiplication between the ES value and the percentage of the category of green present in the area under investigation.

For what concerns the provision of services, related to the capability of a green area to supply not only comestibles but also ornamental and genetic resources, the higher values are in the periphery, where the agricultural areas are present, and where domestic vegetable gardens are more widespread thanks to the availability of space. For the cultural services, connected to how humans per-

Figure 5. ESs total provisions.



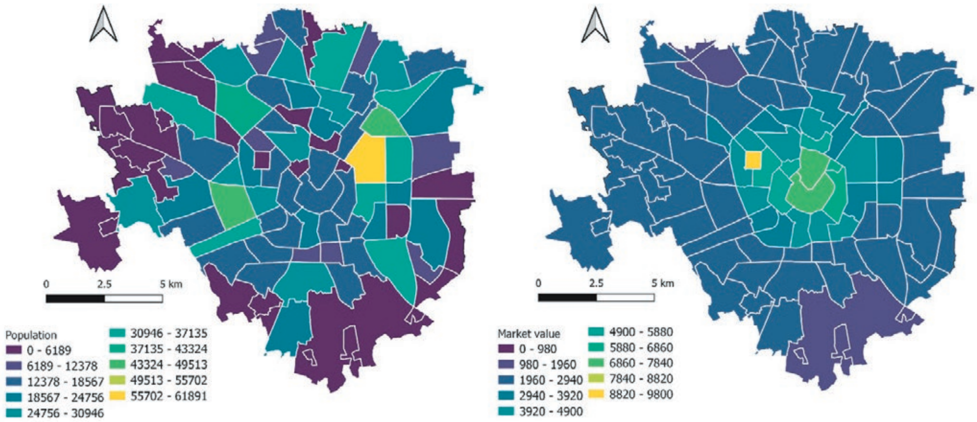
ceive the urban environment, their performances are strictly associated with the presence of public parks and garden. In the regulation of services, aimed at understanding how human being are manipulating the natural environment, uncultivated / abandoned areas have a central role since allow the growth of spontaneous vegetation, essential for the survival and the spread of life of insects and small animals, mammals and reptiles. On the other side, traffic islands negatively affect the climate change and the air quality compromising this ES. The ecological integrity, which involves all the biodiversity aspects and the capability to support and preserve different organisms, also in this case, it is guaranteed where different typologies of green areas coexist.

By reading Figure 5, which shows the total provision of ESs in each NIL analyzed, it is clear how the higher values are scored by areas located in the periphery while the performances decrease by moving to the city center since characterized by a highly urbanized environment.

4.2 Second phase

This second part of analysis involves the investigation of extrinsic characteristics that could influence the liveability and the daily life of the neighbourhood.

Figure 6. Population density (left) and market value (right) maps.



In detail, issues that could be affected or could affect green areas have been selected to understand if potential correlations exist and could determine the choice of possible design strategies. In fact, the provision of public services and the easy accessibility can improve the quality of urban spaces while information about the market value of houses could confirm the studies about the increment of price due to the presence of green areas (D'Acci, 2014).

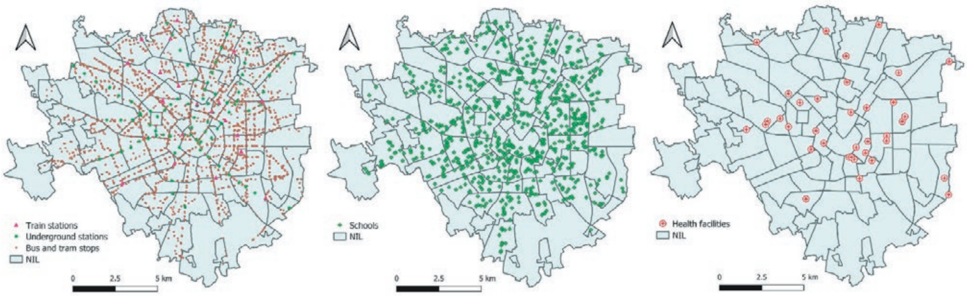
As it has been already mentioned in the methodological framework section, in this context it has been judged as suitable to study the population density, the market value and the social value, meant as the presence of specific services. Figure 6 shows on the left side the map concerning the concentrations of population while on the right the average market value for residential buildings.

For what concerns the population density maps, the most populated areas in the Municipality of Milan are those located around the city centre, where are present neighbourhoods undergoing economic and social development such as Isola-Garibaldi and Loreto while those located at the outskirts are characterised by a low urbanized context. Considering the market value, as it was predictable, central dwellings present a higher price than those at the border of the city.

For the social value (Figure 7), the presence of three different services have been detected, and in detail, public transport stops, schools and health facilities. In fact, to contextualise the ESs produced by each NIL these points of interests have been considered.

The analysis consists in calculating the square meters of green areas present in a buffer of 500 m from the different points and then for each of these three indicators a final mean of the green areas has been performed (for each NIL) to obtain a single result. This distance has been chosen because can be covered within 10 minutes of walk and it was also previously used to study the role of the urban green on the life quality (Klompmaker et al., 2018; McMorris et al., 2015). The selection of these indicators has been guided by the objective of mapping public services which enhance the urban quality of a neighbourhood (Oppio et al., 2018).

Figure 7. Social value maps: public transport stops (left); schools (centre); health facilities (right).



5. Discussion of the results

5.1 Descriptive statistics

To compare results obtained by the different indicators analysed and understanding possible correlations, performances have been standardized in a scale from 0 (worst value) to 1 (best value) in relation to the maximum values scored within each rank.

Among the aggregation procedures available within the MCDA, it is it possible to mention three main categories: compensatory, partially compensatory, and non-compensatory methods. By applying the first one, a weak score obtained in one criterion is compensated by a good score obtained in another one, for the second method the process is composed by two phases where the role of the DM is important in order to get supplementary judgements about the evaluation, while the third methodology is based on the generation of decision rules (Dell'Ovo et al., 2020). Within this context, since it has been judged as not necessary to define specific thresholds of acceptability or rules, a compensative method has been selected. In fact, values standardized have been aggregated by using the Weighted Sum Model (WMS) and by performing a neutral scenario, i.e. by assigning the same influence to the different indicators:

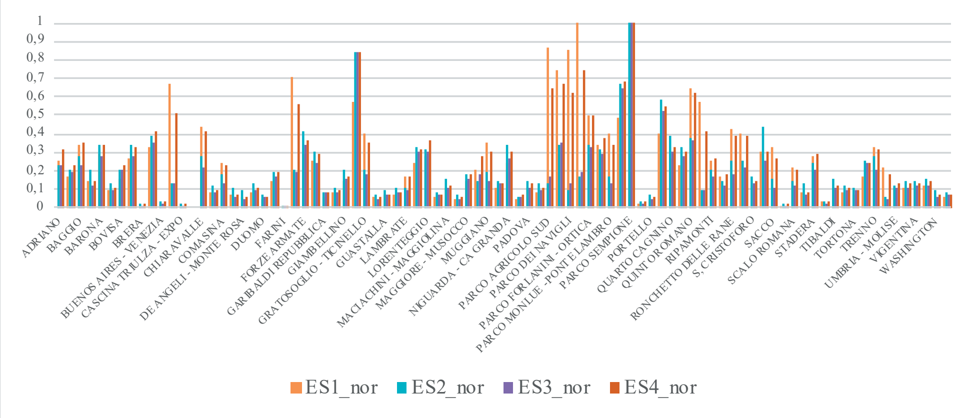
$$V = \Sigma W_i X_i \quad (1)$$

where:
V value represents the total score obtained in the final rank;
W_i is the normalized weight of i-th objective;
X_i is the standardized score (Fishburn, 1967).

Figure 8 shows scores obtained by each NIL for the four categories of ESs analysed and, except for few sporadic cases, they grow and decrease evenly and this trend detects a correlation among the factors under investigation.

By combining partial values of the four categories of ESs and comparing the results with the population density and the market value it is possible to observe

Figure 8. Standardized values for the four categories of ESs.



how there are no correlations or proportion among data investigated (Figure 9). The high score obtained under one characteristic does not determine the increment of the others, indeed, areas with a high population density, usually are those with a lower market value and a medium provision of ESs.

On the contrary by reading the results obtained by Figure 10, on average, NIL with a greater presence of services close to green areas also provide a higher value of ESs.

The analysis offers a visualization of the combinations among all the indicators and to obtain good conditions for the life quality in a NIL the best integration between the presence of a) quality green areas, b) high provisions of ESs, c) facili-

Figure 9. Comparison between population density (pop_nor), market value (OMI_nor) and total provision of ESs (ES_tot).

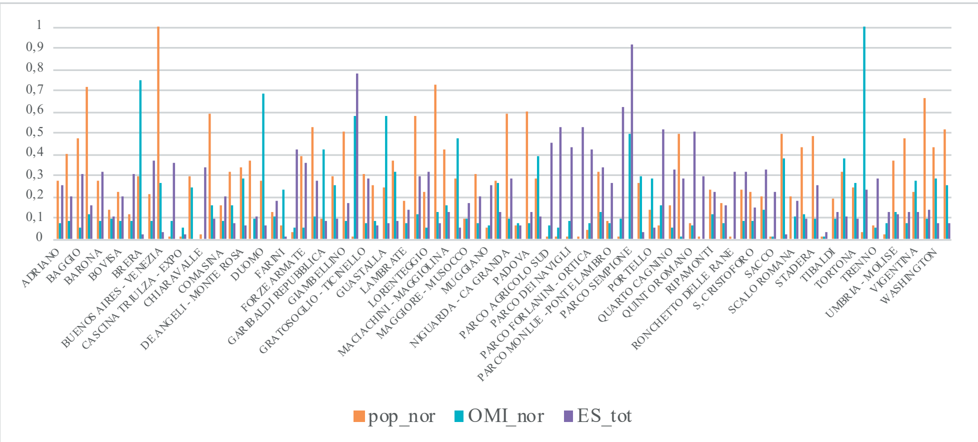
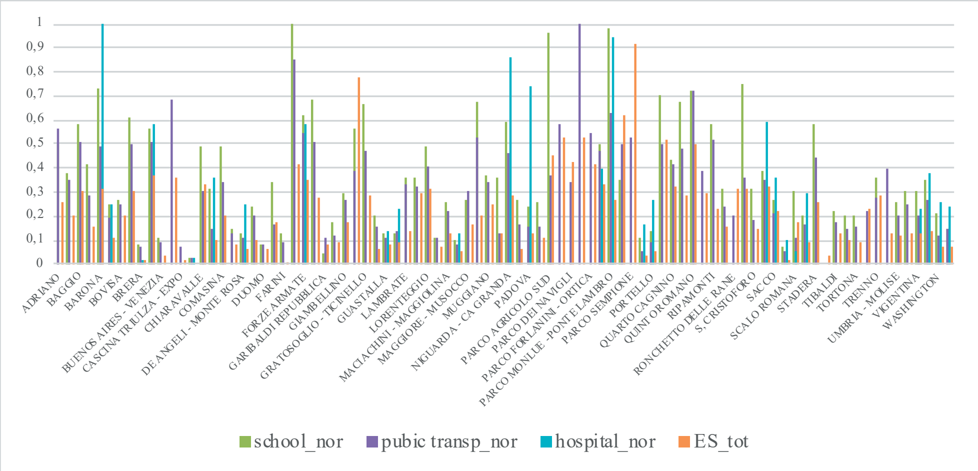


Figure 10. Comparison between presence of services and total provision of ESs.



ties for the population, d) density of the people living there and e) their economic status should be guaranteed.

5.2 Aggregation of the results

Even if the partial results allow to have an overall picture of the situation in each NIL, the final aggregated value could help in understanding which are the more critical areas and how it is better to intervene to plan design actions. In detail Figure 11 shows a comparison between the first phase of analysis and the second phase presented in the methodological framework. Here, more than in other graphs previously presented, it is clear how a gap exists between the provision of social value and the provision of ESs, in fact where intrinsic characteristics perform with a high value, the extrinsic ones obtained a low value and the opposite. This final result could strongly support the allocation of resources and the planning of strategies to implement most critical issues.

In order to complete the analysis, Figure 11 shows moreover the final total value concerning the quality of each NIL obtained by aggregating the two phases performed where, among the 88 NIL, the worst value ranked is 0,02 while the best one is 0,57.

6. How to support the design process

Considering the previous results and the analysis performed, it is possible to both understand criticalities and strengths of each NIL. Within this context planners, architects and policy makers can be supported and guided in providing new

Figure 11. Comparison between the first and the second phase presented in the methodological framework and total quality.

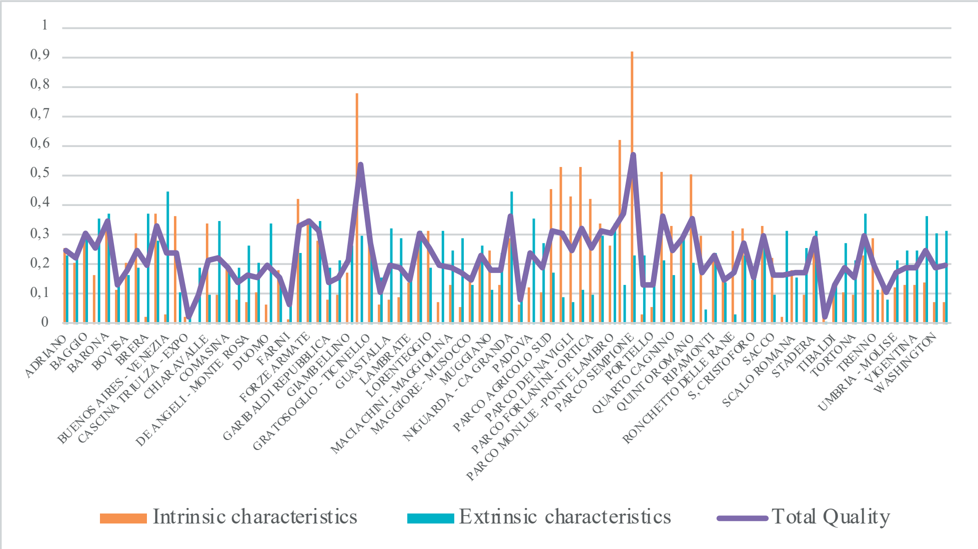
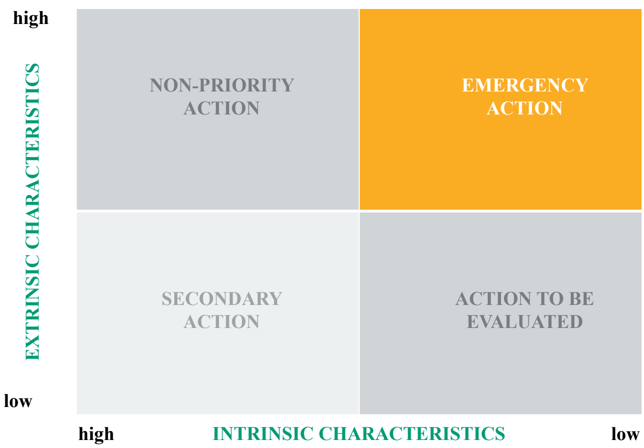


Figure 12. Priority matrix.



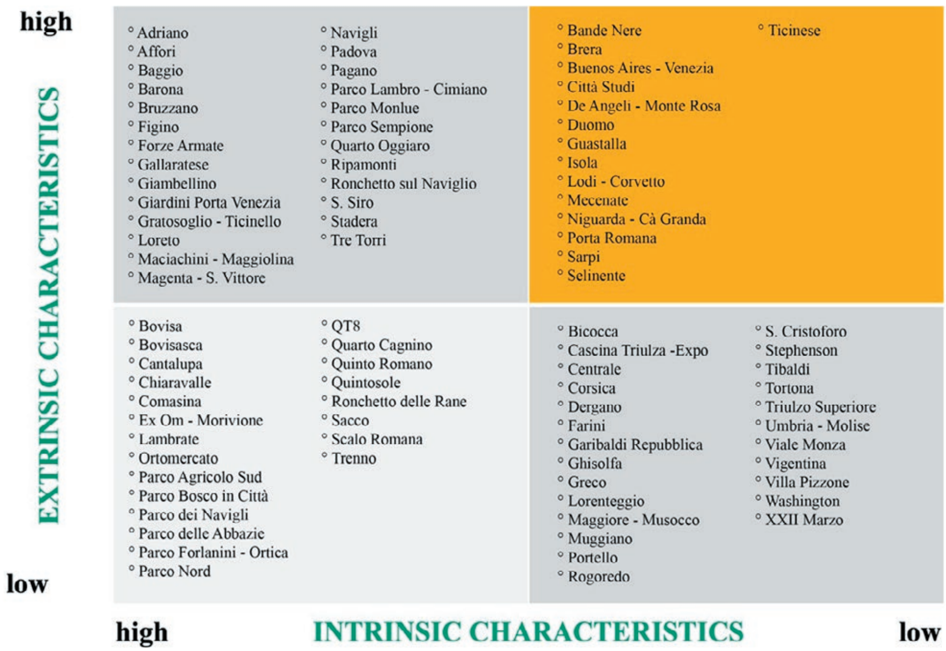
strategies and design actions aimed at improving the overall quality of the city. In fact, given the idea of having good quality conditions when both extrinsic and intrinsic characteristics perform a high value, it is possible to structure a priority matrix aimed at understanding when it is urgent to intervene and when an action is secondary. Figure 12 provides an example and a support with the objective to order and structure all the results previously stated.

The matrix has been framed by considering intrinsic characteristics (horizontal axis), resulted from the first phase of analysis concerning the provision of ESs and extrinsic characteristics (vertical axis) resulted from the second phase and concerning the aggregation of the population density, the market value and the social value. As it is possible to see, for the horizontal axis values are descending (high-low) while for the vertical one are growing (low-high). The matrix has been further divided in four quadrants aimed at defining the priority of the actions. The high value obtained by the extrinsic characteristics and the low value obtained by the intrinsic ones determine a situation where strategies and actions are urgent, while when both performs with a low score the priority should be evaluated case by case according to the context. When both perform with high value the design is not priority while when the provision of ESs is high and the extrinsic features are low, the action is of secondary importance.

The matrix, in this specific case could be used to evaluate the overall quality of each NIL and in understanding which should be improved, while more in general could be useful in supporting the decision and design phase for the development of urban plans or projects aimed at implementing the provision of green spaces.

Figure 13 tries to synthetise the first results obtained by classifying the 88 NIL considering the matrix previously presented and in detail how they behave against to the extrinsic and the intrinsic characteristics. For what concerns the classification in high and low for each axis it has been evaluated the median value for both characteristics investigated in order to define a threshold relative to the case

Figure 13. NIL classified by considering the priority matrix.



study analysed and not absolute one. For the extrinsic the median value is 0,22, it means that NIL with a score ≥ of it are classified as high while < are classified as low, while for the intrinsic the median value is 0,17.

This first analysis can help DMs in understanding which area of the city deserves to be rethought and possibly improved. The limits of the study are given by the analysis developed on the screen with all the criticalities given by the lack of survey on the site and questionnaires aimed at understanding the real perceptions of citizens. Moreover, the framework defined, and the aspects considered could be implemented in order to have a further and deeper awareness of strengths and weakness of the context under a multidimensional perspective. By the way this first attempt of classifying NIL in level of priority for a possible design actions could be at the base of a preliminary analysis aimed at providing a general overview of the city.

6. Conclusions

In the last years, an increasing number of papers has focused on ESs by analysing different features, methodologies, and environment where they are generated. The paper contributes to the scientific debate by applying the UESs concept in the definition of the ESs in the Municipality of Milan. Furthermore, the UESs have been measured with the approach developed by Burkhard et al (2009), mapped and aggregated in in the MCDA environment.

The UESs allow to encompass in an unique set both natural and human-derived services and enhance the effectiveness of the measurement of the ecosystem services in the urban environment where the trade-off and the combined impacts of natural factors and human activities describe the liveability of the cities. The paper focuses on the public and private services, including housing, education and health care, but the contribution of the social activities (e.g. bottom up initiatives, social innovations, citizens' associations) is missing. Nevertheless, they are key elements of the social cohesion and might be token over in the list of ESs. The approach should be implemented by including them in the set of indicators.

Second, the Burkhard, et al. (2009) method is useful, effective and easy to apply. Although it risks trivializing the complexity of the UESs, on the other hand it incisively simplifies the process and allows to compare the results with other case studies analysed under the same approach.

Moreover, the MCDA, based on the concept and method described above, provided a sound support to the decision process and the landscape design at NIL and municipal scale.

Finally, the findings suggest that our approach can help DMs in defining the targeted and tailored strategies to rethink and improve the urban environment by focusing on the most strategic areas, according to levels of priority.

New research perspectives would be aimed at addressing the approach to the design action. The general overview, based on secondary data, might be enforced by primary data collected on the site aimed at understanding the real perceptions of citizens.

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Evaluation of environmental impacts of historic buildings conservation through Life Cycle Assessment in a circular economy perspective

Decarbonizing the economy is one of the main ambitions for the European Union. The construction sector contributes to global warming, during all buildings life cycle phases. Greenhouse gas emissions are present in the whole process of construction, use/operation and dismissing/demolishing. The Life-Cycle Assessment (LCA) is an evaluation approach to assess CO2 and other greenhouse gases emissions during the whole life cycle of a building or product. The aim of this paper is to test the LCA methodology for the evaluation of environmental impacts of historic buildings, towards a circular economy approach in the adaptive reuse of cultural heritage. The case study is an abandoned monastery in Salerno, Italy. Results show that LCA can effectively inform the design phase of cultural heritage adaptive reuse, comparing different conservation and design alternatives.

1. Introduction

Decarbonizing the economy and particularly the energy sector is one of the main ambitions for the European Union towards 2050 sustainability goals, to maintain global warming within the limit of 1,5 degrees increase (IPCC Report). Already since the Paris agreement, in the European Green Deal and in the United Nations Framework Convention on Climate Change, there has been reference to the need of tackling climate change by encouraging actions aimed at reducing carbon emissions. Many European countries have agreed to draw up all development plans for the future with the objective of achieving zero net carbon by 2050, through the use of innovative technologies in every sector.

The objective of reducing carbon emissions needs to be achieved in cities and regions. The Agenda 2030 for Sustainable Development of the United Nations with the Sustainable Development Goals (United Nations 2015) has already set targets to make cities and human settlements inclusive, safe, resilient and sustainable (SDG 11), to ensure access to affordable, reliable, sustainable and modern energy (SDG 7) and to ensure sustainable consumption and production patterns (SDG 12), decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles. The United Nations New Urban Agenda (United Nations 2017) at article 71 strengthens this vision recommending sustainable resources management and the reduction of greenhouse gas emissions.

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Cities account for between 60 and 80 per cent of energy consumption and generate as much as 70% of human-induced greenhouse gas emissions (United Nations 2015). The concepts of "post-carbon cities", "zero-carbon cities" and "carbon neutral cities" have raised attention in the last years to address the challenges of global warming, striving to find effective strategies for cities development able to reduce climate changing carbon emissions.

The concept of "post-carbon cities" has been explored in recent years, following the acknowledgment of the need of decarbonising cities and the economy. The concept of "post-carbon cities" signifies a rupture in the carbon-dependent urban system, which has led to high levels of anthropogenic greenhouse gases and the establishment of new types of cities that are low-carbon as well as environmentally, socially and economically sustainable (Fujiwara 2016). Post carbon transition has gained momentum in the institutional spheres and researchers, as "an adoption of new forms of energy and adaptation to the climate change that is already taking place" (European Commission 2007; Vidalenc & Theys 2013). Post carbon cities must reach a massive reduction of greenhouse gas emissions (GHG) by a factor in 2050 of four compared to 1990, a near self-sufficiency in carbon fossil fuels – oil, gas, coal – and develop the capacity to adapt to climate change (Meeus et al. 2011). Post carbon cities is proposed as a concept allowing to put in a nutshell energy and climate issues. Resilience with regards to oil price rising and supply disruption is one of the key challenges addressed by post-carbon cities.

The "zero-carbon city" concept is based on lower-carbon emission level. Zero-carbon cities avoid carbon emissions and realize their functions adopting low-carbon structures and technologies, aiming at balanced development of economy, society, and environment (Zhao et al. 2011), establishing "science-based carbon reduction targets, policies and action plans, including governance and capacity building to enable them to contribute to the successful implementation of the Paris Agreement and the EU's strategic vision for carbon neutrality by 2050" (URBACT 2021).

Adopting a similar perspective, the "carbon neutral city" works to achieve carbon neutrality by strongly reducing carbon emissions through technologies, governance and funding tools, peer learning, transformational leadership, better communication, and collective action (Carbon Neutral Cities Alliance 2020, 2021). According to research, city level government can foster carbon neutrality by removing carbon emissions from municipal district heat production and promoting carbon-free energy production, regardless of geographical location, as other measures are mostly "outside the jurisdiction of the City, which outsources the responsibility for the majority of carbon neutrality actions to either private properties or national actors with broader boundaries" (Laine et al. 2020).

The built environment and building construction sectors are one of the main sources of greenhouse gas emissions and resources depletion, both in the construction and in the operation phases. The existing building stock in Europe represents the 80-90% of all buildings that will exist in 2050 (World Green Building Council 2019), while buildings are responsible for the 40% of energy consumed in Europe (European Commission 2019). Therefore, to reach the ambitious Europe

2050 objectives of GHG emissions reduction it is fundamental to address the existing building stock implementing retrofit interventions. In Italy, the Law n. 77/2020 has increased to 110% the fiscal incentives for energy retrofitting of existing buildings, identifying key interventions (insulation, heating) and side interventions (energy efficiency interventions, photovoltaic, electric vehicles charging systems). This Law is expected to give rise to enhanced investments in energy retrofitting and energy efficiency, climate-proofing a large part of the national building stock. Between all existing buildings, historic buildings present higher difficulties in energy retrofitting, since they are protected by heritage conservation laws and regulations. Key interventions such as insulation of walls and roofs, as well as other interventions such as photovoltaic panels or new windows, are barely allowed for those buildings that present historical and artistic elements, while costs of retrofitting are generally higher due to the peculiar solutions, technologies and materials to be employed in historic protected buildings to avoid the loss of cultural values while implementing energy retrofitting. Recent studies and practice in energy retrofitting of historic buildings have attempted to reach ambitious objectives of 'zero net carbon' or "near-zero emissions" (Historic England & STBA 2015; Historic England 2018). Various elements influence energy waste in historic buildings: orientation, exposure to sun, wind and rain, shape, materials, heating and cooling systems. Green solutions for historic buildings include hygroscopic insulation, wood fibre panels, mineral wool, lime plasters with cork and hemp.

Based on the calculation of operational energy according to structural, materials and uses criteria, "zero net carbon" buildings are most likely to be found in new construction rather than in historic ones. However, greenhouse gas emissions are present in the whole process of construction, use/operation and dismissing/demolishing, highlighting the need of a full accounting of greenhouse gases during the whole life-cycle of the building to assess the overall sustainability of construction processes and take more effective choice for sustainable building management. The "embodied carbon" concept emerged in the last years to define the amount of CO_2 embedded in materials and production processes, including extraction, transport, processing, using and finally demolishing and wasting (end-of-life) phases. The Life-Cycle Assessment is an evaluation approach that seeks to assess, between other impacts, also CO_2 and other greenhouse gases emissions during the whole life cycle of a product. It has been applied to industrial production and to buildings adopting various methods and tools. In the life-cycle perspective, the GHG emissions from historic buildings are considered not only in the operational phase, but from materials extraction to end-of-life. This perspective changes the point of view in sustainability assessments, highlighting the environmental benefits of reusing existing assets with high 'embodied carbon' instead of producing new ones. This is exactly the perspective of the emerging circular economy model, that strives for the reduction of natural resources depletion and greenhouse gas emissions through reuse, repair, refurbishment of existing products and buildings (Ellen MacArthur Foundation 2012, 2015; Ellen MacArthur Foundation & CE100 2016).

Many historic buildings are currently far from being "climate-proof", while a significant part of them is in a state of abandonment or underuse, waiting for new uses and functions. The adaptive reuse of cultural heritage buildings can be an opportunity to implement the circular economy in the historic built environment, if a life-cycle approach is adopted to assess the environmental impacts of reuse vs. new construction. The Life-Cycle Assessment can be a valuable method to stimulate policy makers to incentivize energy retrofitting interventions in existing heritage buildings, providing evidence-base of the environmental benefits of reusing vs. constructing new "zero net carbon" buildings. Moreover, the adaptive reuse of cultural heritage can have many additional positive impacts, for example on urban regeneration and enhanced attractiveness, jobs creation in heritage-related sectors (economic spill overs), as well as citizens' identity, civic responsibility and people wellbeing (CHCfE Consortium 2015; Fusco Girard & Gravagnuolo 2017; Gravagnuolo et al. 2017; Gustafsson 2019).

The interest in adaptive reuse of building as an alternative to demolition for the benefit of the society has been largely investigated. "New uses for old buildings" were already addressed by Cantacuzino (1975) and Reiner (1979), stressing the opportunities in "recycling" buildings, even if not focusing on heritage buildings specifically. English Heritage (1998) explored conservation-led regeneration, while more recently, the reuse of historic buildings has been addressed by Historic England (2013), who proposed the concept of "constructive conservation". Careful assessment of the impacts of adaptive reuse projects in multiple dimensions can help owners and potential investors and managers of cultural heritage buildings / sites / landscapes in taking informed choices to avoid abandonment of cultural heritage and generate economic opportunities through its adaptive reuse. However, well-established methods are mostly related to traditional cost-benefit analysis or heritage values assessment oriented towards preservation objectives without considering a more complex and holistic perspective (Gravagnuolo & Girard 2017). According to Mısırlısoy, and Günçe (Mısırlısoya et al. 2016), the main aim should be preserving historic-cultural values and the authenticity of the building and its context; however, economic sustainability is important to ensure longer term sustainability of adaptive reuse interventions in the built heritage. The environmental perspective in cultural heritage adaptive reuse has been addressed by Foster (Foster 2020), identifying 46 strategies for circular economy implementation in the adaptive reuse of cultural heritage. Focusing on the environmental perspective, besides the mentioned multidimensional benefits of cultural heritage adaptive reuse, the embodied carbon assessment can provide valuable information to sustainably manage the historic built environment.

The European Standard EN 16883:2017 provides guidelines for sustainably improving the energy performance of historic buildings, e.g. historically, architecturally or culturally valuable buildings, while respecting their heritage significance. It acknowledges the importance of the assessing the whole life cycle of a building by stating that "historic buildings should be sustained by respecting the existing materials and construction, discouraging the removal or replacement of materials /.../ which require reinvestment of resources and energy with additional carbon emissions" (European Committee for Strandardization 2017). A study of Historic Scotland in 2011 already highlighted that sustainable refurbishment of historic buildings should also consider the embodied energy and long-term life cycle environmental impact (Menzies 2011). However, methodologies for embodied carbon assessment in buildings can slightly differ and harmonization and benchmark needs to be addressed (Menzies et al. 2007; König & De Cristofaro 2012).

While not specifically focusing on historic buildings, the recent collection of studies edited by Della Torre et al. (Della Torre et al. 2020) highlighted the importance of regenerating the built environment from a circular economy perspective. Specifically, Giorgi et al. (Giorgi et al. 2020) underlined the importance of applying the circular economy concept to the built environment and the current necessity to renovate a large part of existing buildings to comply with carbon reduction objectives. Within a circular approach, buildings are considered "material banks" and materials reuse/recycling is promoted. The study identifies policy improvements, strategic partnership, and the environmental and economic life-cycle assessment tools for supporting decisions to support the transition towards a sustainable circular building regeneration process, assessing sustainability from an economic and environmental life cycle point of view.

Shetabi (Shetabi 2015) highlighted also that repairability, rather than replacement of historic buildings, provides the opportunity to sustain local craftsmanship and building knowledge, as well as extending the life of products, keeping waste to a minimum. This author indirectly identified a circular economy perspective in the adaptive reuse of cultural heritage, remarking aspects related to reduced wastes as "building components do not end up in landfills". Shetabi argues that "older buildings, especially those built before 1920, were often constructed from durable, high-quality materials (such as exterior masonry) with low embodied energy per time of use since original environmental impact is divided by length of use". Thus, today's less durable material, even if they involve less energy and emissions in production processes, may require frequent replacement which "combined with the energy needed for removal and disposal, results in higher total embodied energy over their life cycle". Thus, Shetabi points out that both cultural attributes and the existing (or lost) energy efficient aspects would be key to a successful adaptive reuse. This is in line with heritage conservation objectives, as heritage buildings are listed and protected to avoid their dilapidation.

The aim of this paper is to test the Life-Cycle Assessment (LCA) methodology for the evaluation of the embodied carbon in historic buildings towards a circular economy approach in the adaptive reuse of cultural heritage, applying it to the case study of an ancient abandoned monastery in Salerno, Italy.

As for the conceptual level, the specific contribution of this paper is framed into the context of evaluating the feasibility and effectiveness of heritage buildings reuse strategies, that is, calculating embodied carbon in historical buildings, within the overall framework of how LCA may support urban planning and design for heritage conservation. As cultural heritage buildings and sites are considered a "cultural capital" for present and future generations (Throsby 1999; Fusco Girard 2019), the option of "demolishing and new build" is not covered in this study, while only conservation measures are taken into account with different intervention measures. Thus, this paper investigates the embodied carbon in restore and reuse projects of existing heritage buildings to test the hypothesis that they are a better option on environmental and climate change grounds, when compared to new construction projects of buildings (in nearby locations) to cater for similar uses.

This study addresses researchers and professionals in the field of cultural heritage conservation, providing a methodology and tools to perform a preliminary Life Cycle Assessment of heritage buildings useful to understand the major environmental impacts of alternatives of conservation and adaptive reuse of cultural heritage, to enhance conservation practice in a circular economy perspective. Given the conservation of cultural heritage and the need of new spaces for mixed urban functions as a fixed target for urban regeneration, two alternative scenarios were compared using LCA methodology: (A) maintain the heritage building in its current state applying minimum conservation work to prevent further decay, and start a new construction project to cater for the same specific use vs. (B) restore/retrofitting and reuse scenario of the heritage buildings.

The following Section 2 presents the in-depth review of selected literature addressing the embodied carbon in historic buildings, as well as the LCA method to assess buildings construction and reuse interventions. Section 3 describes the methodology employed to assess the embodied carbon and defines the two cases scenario. Section 4 presents the case study of the ex-monastery in Salerno, Italy, while Section 5 focuses on LCA scenarios in detail for the calculation of carbon equivalent emissions in all life-cycle phases. Section 6 discusses the results and Section 7 presents the conclusions, pointing out the limitations of this study and the open fields for further research.

2. Embodied carbon in historic buildings: a review of recent literature

To develop this study, the available definitions and methodologies for embodied carbon assessment in historic buildings have been analysed. A search of the relevant literature was performed, including scientific papers on peer-reviewed journals, scientific books, grey literature from institutions and research centres, and policy documents. Sources of data were diverse: Scopus/WoS database, google search, institutional databases. The typology of documents varies from meta-analysis of the literature in the field, to best practice analysis, to policies, statistical data and guidelines. The criteria for selecting relevant literature was the presence of at least two of the following aspects: historic buildings, embodied energy or embodied carbon assessment, LCA methodology. A first search in Scopus database was performed, but only one relevant paper was retrieved. Therefore, a "snowball" search was implemented starting from the references of this key paper and additional grey literature reports were retrieved from the web. By reading the first sources, some related key topics emerged, which were explored through side-searches on Scopus/WoS database and web search. Even if the literature review was not the focus of this work, this phase of the research contributed to validate the initial research question and highlight emerging issues in the field of research. It was decided to focus on the most recent literature (last three years 2018-2020) and include existing reviews in order to ensure completeness with respect to previous studies and identify open research questions that could be addressed within this study.

First, to focus on the most relevant studies in line with the research objective of this work, it was chosen to start from a Scopus/WoS search using the keywords "LCA" and "buildings". This search retrieved 3,369 documents up to year 2020. Then, it was chosen to specify the search by including only most recent papers from 2018 to 2020, reducing the number of studies to 1,247 documents. Within this group, the additional keyword "Heritage" was introduced, which further limited the number of studies to 60. Between these papers, only 31 studies focusing on "embodied carbon" were selected and analysed more in-depth by reading all abstracts. Many documents were not specifically focusing on heritage buildings, thus they were excluded from further analysis as cultural heritage poses specific issues on values conservation that limit the range of compatible interventions. Thus, only studies focusing on heritage were considered. Also, general literature reviews not focusing on the embodied carbon aspect of LCA were excluded, as well as other studies focusing on specific materials or architectural typologies. Based on these considerations, only one paper of Berg and Fuglseth (2018) was focusing on the specific topic of this research, by comparing two options of historic building management – (1) refurbishment and (2) demolition & reconstruction – focusing on embodied and operational energy to discuss pros and cons of both in a decision-making perspective. Starting from this study, additional sources were retrieved through web search addressing "grey literature", using the same keywords and method. From this search, additional 3 reports were included which focused on embodied carbon in historic buildings, the most relevant one in terms of outreach to the general public was a study developed by Historic England on "reuse and recycle to reduce carbon" in historic buildings (Historic England 2020). Starting from reading the initial key sources and reports, additional literature was found on LCA methodology (Bionova Ltd, 2018), as well as review papers on similar topic (Buda & Lavagna 2018; Angrisano et al. 2019; Wise et al. 2019). By exploring the literature selected, it emerged that BIM and LCA integration can be considered as a relevant aspect in the application of LCA to historic buildings, thus the most recent review papers were retrieved from Scopus search, using the keywords "BIM", "LCA", "integration" (54 results), and then limiting the search to review papers published in the period 2018-2020. From this search, only 6 documents were selected and analysed by reading the abstracts. In this group, the paper of Potrč Obrecht et al. (2020) was read more carefully as it provided useful information for this research work. The same literature search and analysis method was applied to another relevant topic emerged from the first studies explored, that is the integration of LCA within design choices in early stage (anticipatory or preliminary LCA), retrieving three papers (Hollberg et al. 2019; Göswein et al. 2020; Hollberg et al. 2020), two of which were explored more in-depth. Finally, two meta-analyses were also retrieved and analysed, on LCA assessments focusing on embodied carbon (Röck et al. 2020) and LCA applicability for buildings design, including considerations on embodied carbon in a circular economy perspective (Schiller et al. 2019).

Table 1. Literature analysed.

Author, date	Typology	Topics
(Berg & Fuglseth 2018)	Scientific paper	LCA application in historic buildings: Energy-efficiency refurbishment versus new construction in Norway
(Historic England 2020)	Report	Embodied carbon in historic buildings: key results from selected studies
(Duffy et al. 2019)	Report	In-depth analysis of embodied carbon in two historic buildings in UK using LCA method
(Dorpalen 2019)	Report	Assessment of refurbishment scenarios of historic buildings based on LCA data
(Bionova Ltd 2018)	Report	LCA to address embodied carbon in building construction process
(Angrisano et al. 2019)	Scientific review paper	Systematic literature review on LCA for buildings
(Hollberg et al. 2019)	Scientific paper	LCA for design purposes (anticipatory LCA)
(Schiller et al. 2019)	Scientific paper	Meta-analysis of LCA applicability for buildings design based on interviews to relevant actors
(Röck et al. 2020)	Scientific paper	Meta-analysis of 650 LCA assessments to identify the impact of embodied GHG emissions on total buildings emissions
(Hollberg et al. 2020)	Scientific paper	BIM-LCA integration for preliminary LCA assessment in the design phase
(Baggio et al. 2017)	Scientific paper	Application of GBC Historic Buildings protocol in the design phase of a historic building renovation
(Potrč Obrecht et al. 2020)	Scientific review paper	BIM and LCA Integration: A Systematic Literature Review
(Wise et al. 2019)	Scientific review paper	Considering embodied energy and carbon in heritage buildings – a review
(Buda & Lavagna 2018)	Scientific review paper	LCA methodology to compare alternative retrofit scenarios for historic buildings: a review

Based on these criteria, 14 most relevant titles are selected and summarized below to provide an overview of why and how LCA can be implemented to assess embodied carbon in historic buildings, and compare different interventions alternatives for enhanced adaptive reuse planning and design (Table 1).

One of the most recent and focused studies addressing embodied carbon in historic buildings is that of Historic England (Historic England 2020) highlighted the need to assess "embodied carbon emissions" in historic buildings, to support conservation interventions. According to the study, the reuse of historic buildings, through their functional conversion, can be considered a viable sustainable and circular strategy to use the amount of energy already spent on their construction, also defined as buildings "embodied energy". This approach to design can support the reduction of raw materials extraction and wastes production. Carbon released for the design and demolition of buildings today is neglected and not calculated in the energy balance of a building. However, the study states that "green buildings are those already constructed". The Historic England report thus focuses on the "embodied carbon emission" calculated for two historic buildings in UK, over a period of sixty years:

- The Former Gas Retort House Birmingham, an industrial building built in 1822 to distribute gas to the city of Birmingham. When it was closed it was converted into a warehouse, then into a movie set, a show venue and finally into a commercial building/warehouse;
- The Victorian Terrace: an abandoned gothic church, converted in a former into a single-family home.

The two reuse projects provided for an energy retrofitting to favour thermal insulation, through the realization of insulated panels on the roof, the realization of double-glazed steel windows behind the existing ones, a raised floor insulated with air heat pumps to heat/cool the spaces. Demolition costs have been mostly avoided, recovering all spaces and materials. A Life Cycle Assessment (LCA) was carried out to assess the "carbon emissions" before and after the retrofit, also trying to identify the amount of energy that should have been used for the demolition of the entire building complex. The two case studies show that their reuse, rather than their demolition, has led to a drastic reduction in carbon emissions, 60% for the Victorian Terrace and 62% for the Former Gas Retort House. On the methodological side, the Historic England report is based on the study on Understanding carbon in historic environment (Duffy et al. 2019). This study presents detailed data on the Life-Cycle Assessment performed for the two case studies, highlighting that "to realize a new building it is necessary to consider the higher capital costs (both carbon and financial), greater production of waste and pollution, increased GHG emissions from the mining, production and transport of new materials, or the social costs of disruption, relocation, urban sprawl and potential loss of community and sense of place. (…) The refurbishment of existing buildings should be a considerable part of government policy to reduce carbon emissions from the built environment and construction industry". The report concludes that the reuse of materials is key to develop sustainable design for the refurbishment of historic buildings, and this should be a focus for the building sector. Data availability is highlighted as a barrier for performing LCA full assessments, calling for more data and research to assess the extent to which the refurbishment of historic or traditional buildings can reduce embodied carbon and operational emissions over a certain length of time. Life Cycle Assessments (LCA) of refurbishment projects may be one way to produce the necessary supporting data. Based on this study, the report on "Valuing carbon in pre-1919 residential buildings" (Dorpalen 2019) confirms that more sustainable design choices can be adopted when taking into account carbon emissions in the whole life cycle, which makes refurbishment of old and historic buildings an effective way to achieve "near-zero emissions" towards 2050. However, it is clear that for historic buildings the embodied carbon cannot become the only indicator for improving design choices.

Adopting a similar approach, Berg and Fuglseth (2018) analysed the net climate benefits from the refurbishment of a residential building from the 1930s with the construction of a new building in accordance with modern building codes, using LCA. This study was considered as a reference point for the present research. The results of this study clearly pointed out that "a careful refurbishment of the historic building is favourable in a climate change mitigation perspective over a 60-year period", while for the new building it would take more than 50 years for the initial emissions from construction to be outweighed by the effects of lower in-use energy consumption.

The report on "Embodied Carbon Reduction in 100+ Regulations & Rating Systems Globally" (Bionova Ltd 2018) uses LCA to assess all environmental impacts generated by a building, from the extraction of raw materials to its demolition. The report defines the amount of "embodied carbon", also called "carbon capital", as the emission of greenhouse gases emitted by a building and the materials incorporated in it, including impacts related to the supply of raw materials, their production, transport, impacts on maintenance, repair or disposal. Five methodologies to address embodied carbon in the construction industry are highlighted: carbon reporting, carbon comparison, carbon rating, carbon cap, decarbonization – with relative examples.

Angrisano et al (2019) performed a literature review on "LCA for buildings", analysing 2,387 records for all fields of the Life Cycle Assessment in the WoS database. The literature study highlights that the LCA is the assessment tool that supports all the processes/protocols able to certificate the buildings sustainability and circularity, analysing three evaluation methods/protocols for buildings sustainability: the LEVEL(s) framework, the LEED certification (Leadership in Energy and Environmental Design), and the GBC Historic Building certification, developed by Green Building Council. All these methods use LCA to perform a full sustainability assessment of historic and more recent buildings.

Wise *et al.* conducted a literature review on "LCA for historic buildings" is of (Wise et al. 2020). This study has identified a developing global interest in this topic after the analysis of scientific literature. The paper results underlined that there are few LCA studies dealing with heritage buildings specifically. Preserving heritage buildings has been shown by several authors to have lifecycle carbon benefits over demolition and rebuild, with temporal aspects of carbon emissions providing additional support for preservation. Some evidence was found for the carbon benefits of traditional materials and these would also help to preserve heritage values. The importance of including recurrent carbon from repair and maintenance activities was identified.

Buda et al. (2018) illustrate that typically, LCA methodology is applied to retrofit interventions considering the existing construction as "a zero-impact datum", with the aim of minimizing its environmental impact. For historic buildings, the LCA is a tool capable to evaluate if the restoring building is less impactful than demolishing.

An interesting study was conducted by Hollberg et al (2019) use LCA as an ex ante evaluation accompanied by multi criteria evaluation processes. A-LCA "anticipatory LCA" (ex-ante) can support to evaluate the stakeholder's different needs and the efficiency of the new materials proposed for its realization. A-LCA was developed for high technology markets, but its basic principle is an interdisciplinary collaboration to integrate social, environmental, and technical aspects for enhanced decision making in buildings construction and refurbishment projects. Moreover, Foster (2020) specifically suggests that LCA can be effectively implemented as (1) a planning and evaluation tool at the start of project development, (2) an exploratory scoping exercise in combination with other participatory methods, and (3) for post project review of circularity. Schiller et al (Schiller et al. 2019) assess material flows in buildings life cycle to support planning towards circular economy. They argue that correct information is currently missing on the great potential for reuse of building materials, a principle in line with the circular economy model. The study proposes the results of interviews to design actors with the aim to define a manual for circular/sustainable design, with a database of materials for LCA analysis. Results showed that more information is needed regarding materials selection, environmental and health risks assessment, deconstruction and recycling, replacement cycles, maintenance budget, life cycle costs integrated with subsidies and incentives assessment. In another study by Röck et al (2020) it is argued that meeting climate-change mitigation needs would require to go beyond operational energy consumption and related GHG emissions of buildings and address their full life cycle. By analysing 650 LCA case studies, the authors highlight that the embodied GHG emissions in the whole process of building production represent 20-25% of life cycle GHG emissions in the best cases, while escalating to 45–50% for highly energy-efficient buildings and going beyond 90% in extreme cases, meaning that further efforts must be put in reducing the embodied GHG emissions, especially for 'highly efficient' new buildings. It may be argued, thus, that refurbishing and recovering historic buildings can be of extreme importance to dramatically reduce the embodied carbon and GHG emissions in the building construction sector, while generating additional social, economic and cultural positive impacts especially for local communities.

In their recent paper, Hollberg et al (2020) highlight that in energy efficient residential buildings the embodied environmental impact makes up about half of the total GHG emitted in a life time of 50 years. This study presents an interesting case of Building Information Modelling (BIM) and Life-Cycle Assessment (LCA) integration to enhance the design process considering sustainability aspects in a whole life-cycle perspective.

Building Information Modelling (BIM), is a methodology of design and management of civil works that integrates all levels of design in a single central and shared 3D model. The volumetric model that is created is therefore unique and integrated and is based on the definition of parametric objects that bring with them, in addition to graphic information, indications of different kinds about the mechanical behaviour, thermal performance, cost, manufacturer and maintenance status of the component. The BIM model becomes a dynamic document that is a spokesperson for the state of the structure and at the same time is able to describe the behaviour of the work along its nominal life. The BIM makes it possible to create a three-dimensional model of the building and to share in real time a multitude of information among the figures involved in the development process of the work (Salzano, 2015).

The study of Hollberg et al. (2020) remarks that LCA on buildings is usually conducted at the end of the design process when the necessary information is available but it is too late to affect the decision-making process, arguing that LCA should be integrated in the early stages of the architectural design process, as these have the highest influence.

There are many interesting scientific papers about the integration between BIM and LCA. Among them, the paper of Obrecht et al (2020) demonstrates that through coupling LCAs with digital design tools, e.g., building information modelling (BIM), it is possible to identify potential negative environmental impacts in the ex-ante design phase and take decisions to mitigate them. This research identified 60 relevant BIM-LCA studies. A total of 16 of the reviewed studies applied LCA during the early design stage, showing as well an increasing use of BIM, because of its potential to store information required for the environmental assessment of buildings, suggesting it should therefore not be overlooked.

A paper that helps to address the issue of LCA in the design phase was developed by Baggio et al (Baggio et al. 2017), that test the LEED rating system, GBC Historic Building protocol developed by the Green Building Council Italy and addressed to Italian historic heritage. The study presents a retrofit design to achieve three objectives: energy saving, preservation of historical architecture, improvement of indoor environmental quality for users. The GBC Historic Building protocol has been used in this study as a pre-assessment and design tool to enhance choices in historic buildings retrofitting and achieve an optimal solution based on multiple criteria.

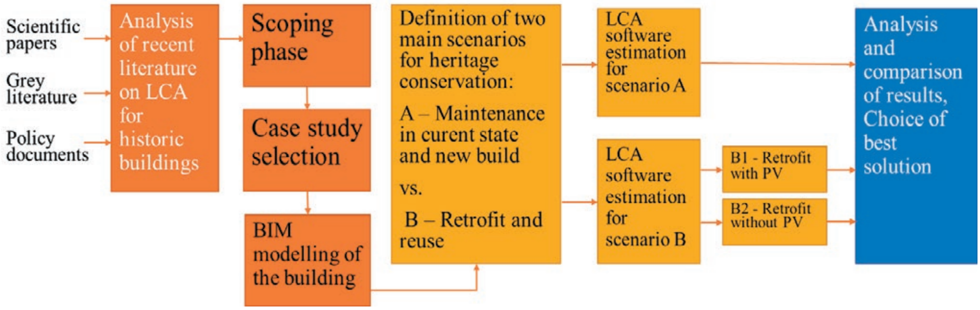
It must be highlighted once again that embodied carbon cannot be the only criterion for choices in cultural heritage adaptive reuse, as in some cases selective demolitions, especially considering modern low-quality additions to the building, could significantly enhance heritage values conservation and the urban landscape. However, embodied carbon should be assessed to deeply understand the carbon footprint of design alternatives, improving choices in the adaptive reuse design and realization process.

3. Methodology

The methodology adopted to assess the environmental impacts of historic buildings conservation alternatives is based on the literature analysed, introducing a circular economy perspective through the Life Cycle Assessment.

The first step of the research was the study of the most recent literature (see Section 2) and the definition of the specific objectives of the experimentation: the assessment of embodied carbon in two scenarios of historic building conservation:

Figure 1. The methodology adopted to assess embodied carbon in historic buildings through the LCA.



(A) maintenance in current state and new build, vs. (B) retrofit and reuse intervention. For scenario B, one further alternative for energy retrofit was simulated, comparing Scenario B1 which included photovoltaic panels and tiles, with Scenario B2 without photovoltaic installations (Figure 1).

The case study identified is the ex-monastery of "San Pietro a Maiella e San Giacomo" in Salerno, Italy, a large cultural heritage building abandoned since more than 30 years and part of a larger complex of 4 historic buildings in the historic city centre, for which the municipality has attempted many recovery projects without success (Lupacchini & Gravagnuolo 2019).

The second step of the methodology is related to the development of a BIM model of the building using REVIT software (Autodesk software[1]), reconstructing in virtual BIM space the main parts of the building with linked database of materials, technological elements and quantities.

Once developed the BIM model and resulting table of materials, building elements and quantities, these data have been put in the LCA software "One Click LCA" (Bionova software[2]) to calculate the embodied carbon in the "existing" scenario.

A BIM model of the historic building was made with the aim to preparing an appropriate project for the redevelopment of the building, through interventions that aim at its carbon and energy efficiency. The design carried out through the realization of BIM Models allows to have all the dimensional data of the building and the data related to the materials used under control. Figure 2 represents the 3D model used for the quantification of materials. Through the BIM, it is possible to calculate the quantities of materials needed to perform the LCA. The software used to create the model is Revit. This software has the characteristic of interacting directly with the "One Click LCA", which is the software used to carry out the LCA of the reuse project.

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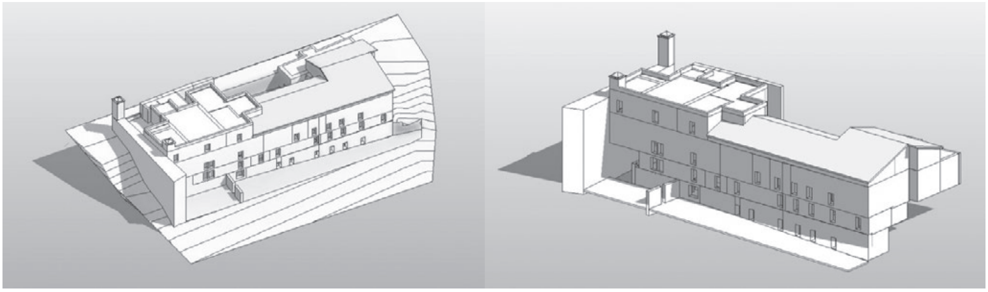
1 See website: https://www.autodesk.com/solutions/bim
2 See website: https://www.oneclicklca.com/

Figure 2. The BIM model of the ex-convent San Pietro a Maiella e San Giacomo.



The biggest revolution in the field of Building LCA has been the introduction of automation: automation has allowed users to significantly cut down the time required to calculate and LCA. What used to take months can now be completed in a matter of hours. Almost all the information required for an LCA is already in the model. If the Revit model includes information about the materials used and the quantities, it can be used to calculate a full LCA. Once installed the Revit plug in in One Click LCA software, the plugin allows the software to automatically import all the necessary information from the Revit model into One Click LCA and map the materials to the extensive material database that includes over 8000 EPDs and generic datasets[3].

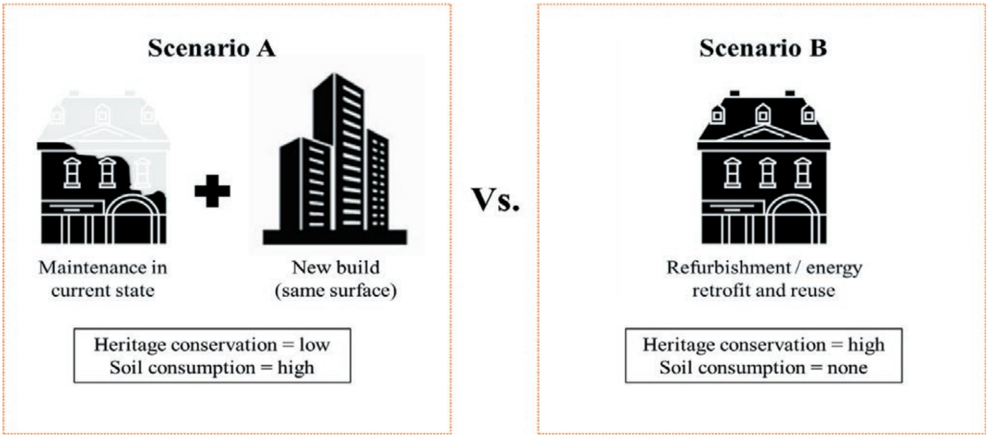
It should be noted that the integration of LCA analysis in BIM allows the analysis of data related to environmental sustainability, which is only one of the aspects of overall sustainability, together with economic and social aspects (Salzano, 2015). The potential of BIM to archive and use the data of each single component, which makes up the building complex, can be used to carry out LCA analyses. From the point of view of the entire life cycle of a structure, it is therefore possible to establish a procedure for carrying out LCA analyses directly from the BIM, integrating the information regarding LCA results into the database of objects supporting the BIM.

According to previous studies (Copenhagen Resource Institute, 2014; Azari & Abbasabadi 2018; Joint Research Centre 2018; Dixit 2019; Dascalaki et al. 2020), the assessment of embodied carbon of buildings need to consider the following phases of the life cycle:

1. Building construction (raw materials extraction, transport, processing/manufacture; site transport, construction). This phase corresponds to the calculation of the “Embodied energy”.
2. Building operations (heating/cooling/ventilation/lighting; maintenance/refurbishment). This phase corresponds to the calculation of the “Operational energy”.

3 https://www.oneclicklca.com/life-cycle-assessment-from-revit/

Figure 3. Alternative scenarios for heritage conservation.



3. End-of-Life (Demolition, Transport). This phase corresponds to the calculation of the “Embodied energy”.
4. Beyond the Life-Cycle (Recycling/Landfill). This phase corresponds to the calculation of the “Embodied energy”.

The LCA has been performed in this case to calculate the “embodied energy” that refers to the amount of energy spent for construction products and processes, for demolition and waste disposal and in the end for carbon saving from materials re-use. The LCA has been performed considering the LEVEL(s) framework and according to ISO 14040 (environmental management-life cycle assessment) and ISO 14044 (environmental management, life cycle assessment, requirements and guidelines).

After this first analysis, two possible scenarios have been simulated: (A) maintenance in current state and new build, vs. (B) retrofit and reuse intervention. The two scenarios are characterized by different levels of built heritage conservation, as well as different impact on soil consumption (Figure 3).

Scenario A foresees the conservation of the heritage building in its current state applying minimum conservation works to prevent further decay. This scenario represents a conservative option that would ensure the transmission of cultural heritage to future generations. However, this scenario would imply that the necessary mixed use functions are shifted to a new building located nearby the site, with same surface. This option would maintain minimum requirements for heritage conservation but would also imply additional soil consumption to build a new building with similar surface.

On the other side, Scenario B implies that the heritage building is refurbished and reused applying compatible materials focusing on energy retrofitting for enhanced energy performances. This scenario would avoid soil consumption and re-generate heritage values through new uses, assumed that they are compatible with its cultural values.

Given these premises, the two scenarios were compared with respect to environmental impacts, considering embodied and operational energy and related carbon emissions. For both scenarios, the LCA software used existing databases that already includes more than 80,000 records and estimations based on data analysis in European countries.

The rules for performing the Life Cycle Assessment are defined by the standards (Bruce-Hyrkäs 2018). The most important standards for building Life Cycle Assessment are ISO 14040 and ISO 14044. Also, construction works specific standards include EN 15978 (LCA standard for construction projects), ISO 21929-1 and ISO 21931-1. Environmental Product Declaration standards is also applied in the LCA software used (One-Click LCA) including ISO 14025, EN 15804 (EPD data) and EN 15942 (EPD format) and ISO 21930.

The following building construction categories and materials have been considered for the LCA assessment in the case of new build (Table 2). Materials were selected based on standard construction elements for high energy performance buildings, ensuring high thermal insulation and generation of energy in site through photovoltaic panels. External walls and façade were designed applying a mix of standard materials to simulate a common typology for mixed use buildings.

A category of "External areas and site elements" has not been considered for this study. Quantities have been included based on the BIM model previously realized.

The resulting calculation of embodied carbon is assessed in "kg CO_2e/m^2" unit, considering the Gross Internal Floor Area of 2,455.50 m^2. This measure allows to compare and benchmark diverse design scenarios. Finally, results were compared to evaluate the "best case" scenario under the environmental point of view, considering the life cycle of the alternatives presented. The following sections presents the case study and the results of the analysis carried out using the LCA approach.

4. The case study

The ex-monastery of "San Pietro a Maiella e San Giacomo" was built in the 14th century, exactly in 1332 and enlarged in 1774 with the construction of a new church. In 1808, it underwent several modifications to host a prison. After the resignation of this function the building was abandoned and today it is in a remarkable state of decay. The building consists of four levels. The first level is occupied by small shallow rooms built close to the pensioner, which originally had a service function. Community service rooms were located on the two upper levels and the monks' cells on the third level. Also, on the first level there is the church, which in height occupies two floors.

From a construction point of view, the size of the building and the rooms that make it up suggest the use of the simplest local construction techniques. It is likely that both the masonry and the vaulted elements are made using the conglomerate technique consisting of freshly hewn stone material of various sizes, brick

Table 2. Categories, typologies and materials used for the LCA calculation through One-Click LCA software.

N.	Category	Typology	Materials Scenario A	Materials Scenario B
1	Foundations and substructure	Foundation, sub-surface, basement and retaining walls	Basic foundations up to 5 m; Excavation works;	None – recovery of existing
2	Vertical structures and façade	External walls and façade	Concrete external wall assembly with external insulation; Fiber cement sheet cladding; Brick walls including mortar with air gap; Lightweight aggregate incl. mineral wool insulation and timber frame;	Existing external walls recovered; Rock wool insulation panels;
		Column and load-bearing vertical structures	Structural hollow steel profiles; Structural concrete assembly for beams and columns;	None – recovery of existing
		Internal walls and non-bearing structures	Concrete internal wall assembly; Steel stud internal wall incl. mineral wood insulation;	None – recovery of existing
3	Horizontal structures: beams, floors and roofs	Floor slabs, ceilings, roofing decks, beams and roof	Gypsum plasterboard; Vinyl flooring; Bitumen sheets for waterproofing of roofs; Structural hollow steel profiles; Mineral wood suspended ceiling assembly; Ceramic tiles; Parquet flooring; Structural concrete assembly for beams and columns; Concrete roof assembly; Concrete floor assembly incl. mineral wool acoustic slabs; Concrete ground slab assembly incl. insulation;	Expanded polystyrene insulation for ceiling; Composite thermal insulation system; Roof waterproofing membrane;
4	Other structures and materials	Windows and doors	Large windows, including steel profiles; External door, from steel and aluminium; Glass wall partitioning system; Wooden doors with PU core;	Ceramic tiles for floors and walls, recovery and partial substitution;
		Other structures and materials	Concrete assembly for stairs and elevator shafts;	None
5	Finishes and coverings	Exterior façade covering	Exterior façade mineral plastering mortar coating;	Exterior façade mineral plastering mortar coating;
6	Building technology	Building systems and installations – it includes the systems for the functioning of the building, such as heating, cooling, electricity, renewable energy systems	Photovoltaic panels installation;	Photovoltaic panels and tiles; (Scenario B2 excluded photovoltaic installations)

Figure 4. The ex-monastery of San Pietro a Maiella e San Giacomo in Salerno, Italy.

and lime mortar. The roofs should have a wooden structure and a brick covering (Figure 4).

According to Municipality data, the building covers an area of 2,455.45 square meters with 234 square meters of external areas.

The municipality of Salerno started a process of evaluation for the adaptive reuse of this cultural heritage building within the Horizon 2020 project "CLIC" (Circular models leveraging investments in cultural heritage adaptive reuse)[4]. Within the Horizon 2020 CLIC project, the municipality conducted a public consultation process for the adaptive reuse of the four large buildings named "Edifici Mondo", involving the local community. The 14 proposals received were selected and further elaborated during a co-design workshop. A mixed-use was proposed for the four buildings, combining public, private and civic/social functions, and creating, around future and traditional arts, culture and eno-gastronomy, a vibrant and inspiring place for a very diverse group of stakeholders looking for opportunities to innovate within a local and inspirational network.

Through the participatory co-design process, the municipality of Salerno was provided with viable alternatives for the adaptive reuse of the historic buildings, which however still require deep renovation to be reused as new cultural and social attractors in the city centre. The renovation to be realized will need to respond to criteria of energy efficiency in terms of operational energy, however current regulations do not foresee a complete assessment of the carbon footprint of the renovation project. Partial demolition and reconstruction could be foreseen in order to enhance energy performances of the historic building, without considering the total embodied carbon of project alternatives.

The analysis of the embodied carbon carried out in this paper provides useful data to support decision making in the very early stage of the adaptive reuse process, in line with the "anticipatory-LCA" approach (Hollberg et al. 2019). The

4 www.clicproject.eu

following section describes the results of the LCA conducted on the adaptive reuse of the historic building, considering the equivalent embodied carbon of the current building "as it was built today", the renovation proposal with energy efficiency criteria, and an hypothesis of demolition and reconstruction.

5. Results

This section presents the results of LCA for the two options considered: Scenario A (maintenance and new built) and Scenario B (adaptive reuse with energy retrofit). Scenario B was further explored by providing two options of refurbishment, one (B1) with deep energy retrofit including photovoltaic panels and tiles installation, resulting in high energy performance of the building, and a second one (B2) which did not include photovoltaic installation, thus its energy performance in the operational phase was slightly lower.

5.1 Current scenario simulation (Scenario A)

According to the data built through the BIM modelling, basic data for the assessment of embodied carbon through LCA were defined (Table 3).

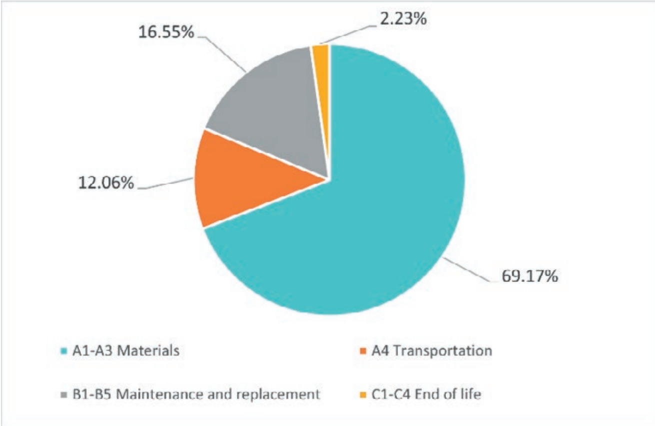
Embodied carbon benchmark was calculated for a fixed 60-year assessment period for all building materials.

The simulation considered that the historic building remains "as is", avoiding refurbishment and transformation works, while a new building with same surfaces was considered to be built in a nearby location. The uses considered were mixed, including commercial and office units (45%), as well as residential uses (55%). Based on this data, the LCA model was built considering materials

Table 3. Historic building data for LCA.

Main factors influencing embodied carbon of the building	Case study data
Address	Salerno, Italy
Type	Historic or protected monument
Age/Period Year built	1332, enlarged in 1774 (new church), major modifications in 1808 to host a prison
Construction typology	Bearing masonry
Use (Residential, Commercial, Hotel, School, Hospital)	No use currently Original use: Monastery
Number of buildings on site	1
Number of floors	4
Gross floor area (m^2)	2,455.50 square meters

Figure 5. Embodied carbon by life-cycle stage in Scenario A.



and typologies of standard modern buildings with high energy performances provided as example for LCA assessments by One-Click-LCA software, adapted to the case according to the quantities retrieved from BIM model and integrating photovoltaic panels and excavation works for site preparation as specific features of this scenario.

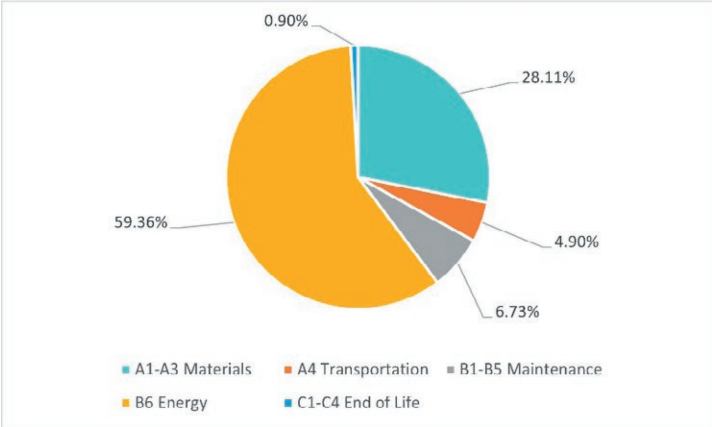
The model allowed to simulate the energy performance of the new building as A4 energy performance certification level, corresponding to approximate 25 kWh / m^2 / year. This data allowed to calculate the operational energy and related carbon emissions over the period of 60 years. Western Europe and European / Italian dataset were used as parameters for the calculations. The "Embodied carbon by life-cycle stage" was also assessed based on the data provided (Figure 5).

Materials extraction impacts for 69.17% of the total embodied carbon, while transport impacts for 12.06%, maintenance and replacement for 16.55% and end of life for 2.23% of the total embodied carbon. This scenario changes when operational energy is considered (Figure 6). Here, the operational energy accounts for 59.36% of the total life-cycle carbon.

The total embodied carbon resulted equal to 3,110 Tons CO_2e and 21.12 kg CO_2e / m^2 / year considering the Gross Internal Floor Area and a period of 60 years. It must be highlighted that for this study not all materials and technologies have been considered, but only the basic structures of the building, that implies the underestimation of the embodied carbon. However, for the scope of this study it was considered sufficient to highlight the distribution of embodied carbon based on the most relevant structures and materials in place.

A further assessment has been conducted to assess the embodied carbon of a renovation proposal for the building, adopting energy retrofitting criteria, materials and technologies.

Figure 6. Life-cycle carbon incl. embodied and operational energy in Scenario A.



5.2 Energy retrofit intervention and reuse simulation (Scenario B1)

A basic energy retrofit intervention has been simulated for the historic building, considering simple enhancement interventions: roof and external walls thermal insulation, ceiling insulation, a Solar panel photovoltaic system complemented by photovoltaic tiles compatible with historic building to ensure renewable energy generation in site, new windows, partial recovery and substitution of pavement and exterior façade plastering. These interventions have been selected as basic energy retrofit interventions adaptable to the characteristics of the case study, based on case studies retrieved from the literature available. The same mixed uses were considered for the historic building: commercial units at ground floor, office units at first floor, and residential uses for spaces at second and third floor. The operational energy was calculated based on the energy performance estimation resulting in achievable A certification level, equal to 30 kWh / m^2 / year. The total embodied carbon resulted 3,043 Tons CO_2e and 20.66 kg CO_2e / m^2 / year, almost equal to Scenario A. The impact of materials extraction was significantly reduced, resulting in 41.99%, while replacement impacted for almost the rest of embodied carbon equal to 57.18% (Figure 7). Moreover, the carbon share from operational energy is much more relevant in the case of refurbishment and reuse scenario than in the new build (Figure 8).

The two Scenarios A and B have been thus compared through the comparison tool, highlighting the embodied carbon due to the renovation (Table 4).

Table 4 shows the Kg CO_2 equivalent generated during the phases of construction, transportation, maintenance and periodic replacement if needed in the time of 60 years considered for the calculation, and end of life with recycling and waste treatment. CO_2 equivalent is a standard metric measure "used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount

Figure 7. Embodied carbon by life-cycle stage in Scenario B.

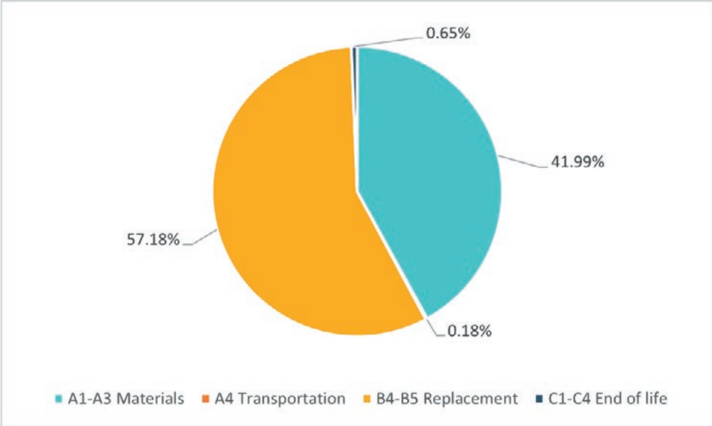
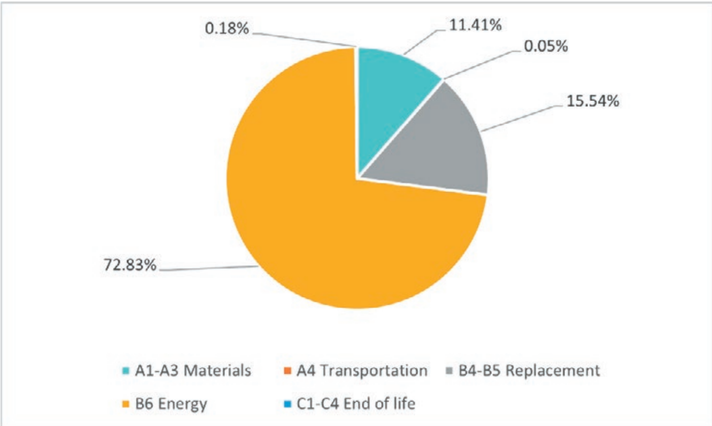


Figure 8. Life-cycle carbon incl. embodied and operational energy in Scenario A.



of carbon dioxide with the same global warming potential"[5]. In the case of Scenario B Adaptive Reuse with Energy Retrofit, the category B1-B5 "Maintenance and material replacement" determines the most relevant increase of carbon emissions compared with Scenario A, as the scenario shows an increase of +130% kg CO_2e. This was expected because the adaptive reuse implies the maintenance of most existing materials on site and, in addition, the use of new materials. However, different choices for the adaptive reuse, involving also the operational energy based on

[5] https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_equivalent

Table 4. LCA comparison performance table.

Life-cycle stages	Result category	Scenario A – Maintenance + new build kg CO_2e	Scenario B – Adaptive reuse – Energy retrofit kg CO_2e	Difference in percentage
A1-A3	Construction Materials	874,224.27	347,193.59	-60%
A4	Transportation to site	152,376.28	1,474.62	-99%
B1-B5	Maintenance and material replacement	209,213.64	472,771.42	+130 %
B6	Energy use	1,846,488.84	2,215,786.61	+20%
C1-C4	End of life	28,148.53	5,354.52	-81%
	Total	3,110,451.56	3,042,580.77	-2%
	Results per denominator: per Gross Internal Floor Area	1,266.99 (kg CO_2e / m^2)	1,239.34 (kg CO_2e / m^2)	
	Results per denominator: per Gross Internal Floor Area m^2 / year	21,12 (kg CO_2e / m^2/ year)	20.66 (kg CO_2e / m^2/ year)	

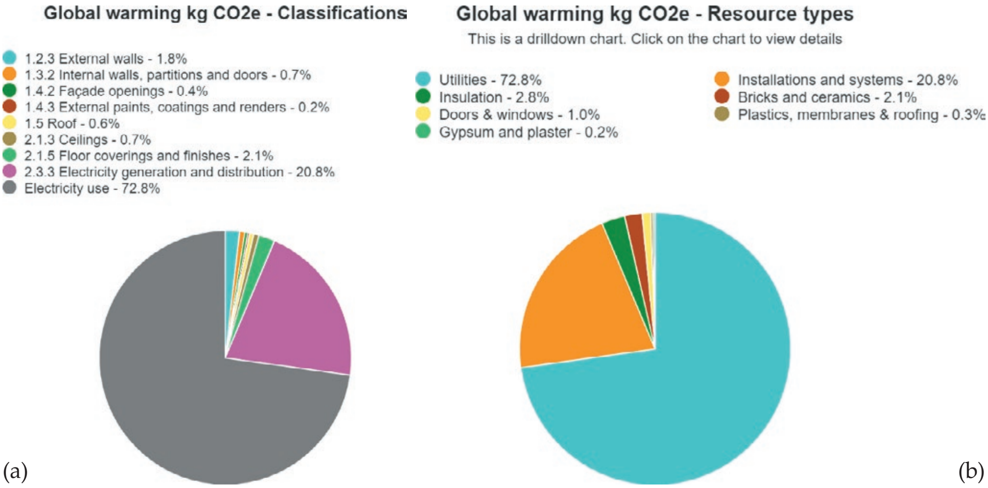
the mix of functions selected for the building, can lead to lower or higher impact in terms of CO_2 equivalents. It is thus clear that careful assessment of alternative technologies and materials, as well as uses and functions of the building, can be of high utility for designers to compare alternative solutions for the adaptive reuse of the building in a life cycle perspective.

The following figures show details of how carbon emissions are generated within the whole life-cycle of the building construction, referred to Scenario B Adaptive Reuse with Energy Retrofit.

Figure 9 (a) shows the distribution of Kg CO_2e generated based on the classification of technical elements of the building. It can be seen that the electricity use generates the most important share of equivalent emissions (more than 70%). Electricity generation and distribution systems through ph

otovoltaic panels and tiles also generate more than 20% of total equivalent emissions. The typical elements that are replaced in a reuse project, such as external walls insulation, finishes and coverings, windows and doors have a low impact on the total equivalent emissions generated. Also, Figure 9 (b) shows the distribution of Kg CO_2e generated based on the specific materials used. Here, again, utilities account for more than 70% of total equivalent emissions, while photovoltaic panels and tiles share a high percentage compared to other construction elements and materials (20.8%). Insulation materials and bricks and ceramics together have the highest impact among the other construction materials (2.8% and 2.1% respectively), followed by doors and windows (1.0%), plastics, membranes and roofing (0.3%) and gypsum and plaster (0.2%). Bricks and ceramics are typical materials used in historic buildings. Figure 10 shows a differ-

Figure 9. Kg CO_2e classifications by Life-cycle stages, construction elements, resource types.



(a) (b)

ent representation of the distribution of Kg CO_2e generated based on materials/resources types and subtypes. Here, operational energy was not included, while construction materials are represented.

Energy production systems have clearly the highest impact compared to other materials used in the refurbishment proposal. Also, between the other materials employed, rock wool insulation and tiles show the highest share of impact. This kind of analysis, facilitated through the use of software based on a high amount of data such as LCA One Click or similar, can provide useful insights to designers in order to choose environmentally friendly solutions for the adaptive reuse of heritage buildings.

5.3 Energy retrofit intervention Scenario B2

As energy production systems such as photovoltaic panels and tiles used for the refurbishment were taking a large share of total carbon equivalent emissions, it was considered interesting to explore a second refurbishment alternative without photovoltaic systems. In this way, the resulting energy performance level in the operational phase was lower, estimated as 45 kWh /m^2 / year. Thus, a simulation of embodied carbon and operational energy consumption with related carbon equivalent emissions was performed (Scenario B2). The resulting amount of carbon equivalent emissions was higher than both Scenarios A and B, confirming previous studies that highlighted the importance of operational energy in the life-cycle assessment (Berg & Fuglseth 2018). Figure 11 shows the comparison between the three options.

Scenario A (maintenance and new build) shows lower equivalent emissions in the operational phase, but higher ones in the phase of materials extraction and

Figure 10. Bubble chart of total life-cycle impact by materials/resource type and subtype, Kg CO_2e.

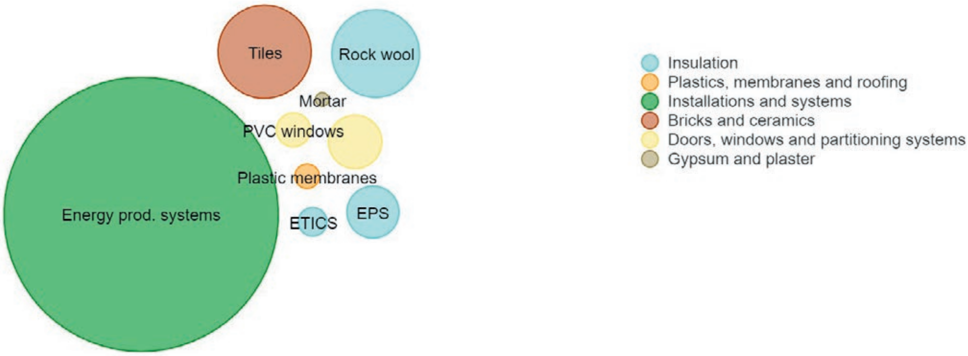
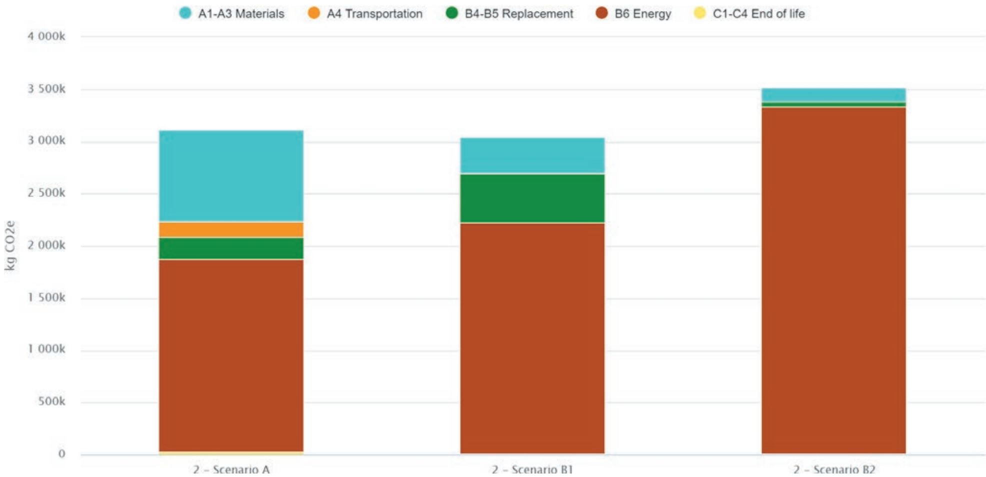


Figure 11. Comparison of carbon equivalent emissions per life-cycle stage between Scenario A maintenance and new build, Scenario B1 refurnishment with PV, and Scenario B2 refurbishment without PV.



transportation. Scenario B1 (retrofit with PV and reuse) implies slightly higher equivalent emissions related to operational energy and replacement/maintenance of materials over the 60 years of reference period calculated, but it also shows lower equivalent emissions related to materials extraction and transportation, resulting in a total carbon emissions level which is slightly lower than Scenario A, as described in previous section. Finally, Scenario B2 presents lower equivalent emissions related to materials extraction, transportation and replacement/maintenance, while operational energy impacts for a larger amount of carbon equivalent emissions, resulting in clearly higher global environmental impact.

6. Discussion

The simulations of cultural heritage building conservation alternatives performed in this paper showed interesting results that support original hypotheses and are comparable to previous studies. The life cycle approach can greatly help designers and decision-makers to consider diverse GHG emissions and environmental impacts not only based on the operational energy performance of the building after construction works, known as the "energy performance" level of the building, but also based on the emissions generated throughout the entire life cycle of the construction works and building (re)use.

The option of maintaining and recovering the existing materials of old buildings applying renewable energy systems coupled with insulation materials and windows for high energy efficiency (Scenario A) would be a far better choice from an environmental perspective, instead of realizing a new building with similar characteristics. Clearly, other considerations need to be adopted which go beyond the equivalent emissions generated in the construction phase, however this data can give useful insights in the choice between different reuse and design options for historic buildings. It also needs to be considered, for example, the conservation of cultural values of historic buildings, which would be enhanced if adaptive reuse, refurbishment and recovery works are realized, compatibly with heritage features – such as in the case studies briefly presented in section 2. Also, if soil consumption is included in the overall assessment of alternatives, by applying multi-criteria decision aid methods (MCDA), this aspect could impact on the final evaluation of the "best" conservation alternative.

As per the limitations of this work, it should be highlighted that not all materials and installations were considered for the LCA, as it was performed as an "anticipatory" LCA in a preliminary design phase, in which no detailed information on the design choices was available. Thus, the absolute results in terms of CO_2e should not be taken as a final data for the specific project, as what is more interesting is the observation of the actual share of CO_2e comparing different life-cycle stages and standard materials. In more advanced design stages, LCA showed a high potential to provide detailed results which would greatly enhance the decision-making process in terms of design and new uses/functions.

As far as operational energy is concerned, a detailed estimation of energy consumption levels according to the foreseen uses of surfaces and volumes of the building would significantly improve the detail of LCA results. Operational energy deserves cautious attention in LCA for historic buildings, as most of the carbon emissions are related to this phase of the life-cycle. The sensitiveness of life-cycle assessment results with respect to operational energy suggests that annual energy consumption estimations should be carefully addressed, linking energy efficiency performance assessments to LCA, possibly through integrated BIM modelling that include both energy certification estimation and LCA. As the assessment was performed in the early stage of the design process, at the scope of comparing different strategies for the conservation of the heritage building, the calculation of operational energy was performed on the base of estimated energy performance.

However, users' behaviour can substantially impact the LCA assessment on operational energy, therefore the anticipatory LCA could be further enhanced by applying data from energy uses in diverse building typologies and for diverse uses/functions. For example, as observed by Berg and Fuglseth (2018), heating volumes would generate different consumption levels with respect to other not heated spaces of the building, as well as office spaces would generate different consumption levels if compared with residencies. In the case of this paper, the detailed estimations of operational energy fell out of the scope of the specific research objective, however this aspect would be worth to be investigated in future research.

7. Conclusions

The aim of this study was not only to assess the embodied carbon and its distribution throughout the life-cycle of a historic building adaptive reuse, but also to explore how LCA can provide important insights in the design phase to make better choices in adaptive reuse processes, taking into careful consideration carbon emissions as one of the key evaluation criteria. The study discussed that current available tools can be successfully employed to perform ex-ante analysis of adaptive reuse choices, adopting an "anticipatory LCA" approach (Hollberg et al. 2019).

This first analysis could be effectively integrated including data on operational energy after the reconstruction phase. However, this fell out of the scope of this specific study, which aimed at exploring the usefulness of including the concept of embodied carbon in choices regarding the adaptive reuse of historic buildings, in a life cycle environmental perspective. As said, other social, cultural and economic criteria should complement the environmental assessments when taking choices on historic buildings reuse. Nonetheless, LCA provided useful insights on the environmental impacts of diverse choices for the adaptive reuse of the historic building. LCA can be useful at the "macro" level of the urban scale, linked with the decision of adaptive reuse alternatives vs. demolishment, maintenance and/or reconstruction, as well as at the "micro" level of the design choices, including choice of materials and technologies.

During the design process for the adaptive reuse of a historic building, different impacts should be evaluated: environmental impacts, impacts on the cultural/historical value, impacts deriving from the compatibility of the materials to be used, impacts related to the accessibility of the building, socio-economic impacts deriving from the attribution of new functions. Ex-ante evaluation can help decision makers in determining new functions and uses of historic buildings.

In heritage buildings management, the use of LCA to assess embodied carbon can be useful also to address some processes that may affect present or future phases in the life cycle: for instance, this is the case of biogenic carbon stored in building materials which may be released because of decay or demolition. "Biogenic carbon is the carbon that is stored in biological materials, such as plants or soil. Carbon accumulates in plants through the process of photosynthesis and therefore bio-based products can contribute to reduce the levels of carbon dioxide in the atmosphere and help mitigate the challenge of climate change. Biogenic carbon within a building product can, therefore, be considered as a "negative emission". This means that during the growth stage of bio-based materials carbon is stored into the material" (One Click LCA 2021). However, high deviation can be observed between different methods available for the assessment of biogenic carbon (Hoxha et al. 2020), thus more research would be needed towards better assessment of net climate benefits of demolition and transformation choices in the life-cycle perspective.

Carbon emissions have a social cost, which is estimated in LCA method. Climate change impacts on human health and ecosystem services, reflected in excessive heat, flooding, etc. have negative effects on people, such as depression, anxiety, stress disorders (Whitmee et al. 2015; Carone et al. 2017; Watts et al. 2018; Gupta et al. 2019). These negative impacts are classified as social costs of carbon. This cost can be variable based on the type of building and type of intervention foreseen. For new building with large floor areas, it can overcome the million euro (based on LCA examples provided by One Click LCA). In the case of the historic building considered in this paper, this social cost is estimated around 50,000 €, however this cost should be considered as underestimated both due to the limited materials and technologies considered, than to the lack of operational energy which would substantially increase the amount of carbon emissions over a 60 years period (and its social cost). The Social cost of carbon could be considered in multicriteria evaluations, as well as in Cost-Benefit Analysis, Life Cycle Cost and Cost-Effectiveness assessments, in order to include this criterion in the choice of the most effective design/project alternative. If correctly accounted, the social cost of carbon could impact on the overall assessment of costs and benefits of alternative conservation choices of historic buildings, in a multidimensional perspective.

A number of tax incentives can be made available to facilitate the practices of adaptive reuse of historic buildings and increase investment in research and innovation for heritage conservation. Investments in the use of biomaterials and nanotechnology for the sustainable and circular design of the adaptive reuse of historic buildings could be highly beneficial, identifying new ways for "zero net carbon" projects.

This study has limitations related to the choice of materials and technologies, which should be more detailed in an advanced design process. However, in a preliminary stage the kind of assessment conducted can provide useful insights for the successive detailed design phases.

More studies and applications of the tool for historic buildings would be needed to allow benchmarks and experimentations. The GBC historic buildings can represent an interesting starting point, while more data and assessments remain necessary for the careful evaluation of the particular traditional and innovative materials, as well as technologies, employed in historic buildings. This study provided a contribution in the advancement of this research field.

Future perspectives of this research include interoperability between dynamic energy simulation software (e.g. Energy Plus), BIM, and LCA, which could be explored in the future. Advanced software and methods could provide useful tools to designers and decision makers, enabling simplified but accurate assessments to support the early stages of decision making, as well as the detailed design, construction works and maintenance stages of historic buildings reuse.

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