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Selection of Core Indicators for the Sustainable Conservation of Built Heritage

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ABSTRACT

This paper presents and discusses the selection of a set of core indicators for the sustainable conservation of built heritage. This core set of indicators was selected by following a two-step methodology: 1) first, a comparative analysis of indicators of two building sustainability assessment (BSA) tools with different approaches was performed by using content analysis to identify common priorities; 2) second, a selection of the indicators according to scale, stage of the life cycle, and coverage of core aspects for sustainable development, following the criteria established by the International Organization for Standardization. The results show that even if current methodologies have different structures, terminology, and priorities, they share common principles that promote a more sustainable built environment. However, by being mostly oriented to the intervention and operation phases, these methods do not have direct application as an assessment framework for the sustainable conservation of the built heritage. To overcome this situation, this research presents a concise set of indicators that can support the development of an assessment tool to ensure the sustainable conservation of existing buildings.

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Assessment; heritage; indicators; sustainability; sustainable conservation

1. Introduction

The evolution of the concepts of "heritage" and "sustainability" shows that they are related both in their common scope — focusing on the ecosystem inherited from the past — and in their aims — to preserve this ecosystem for future generations (Gonçalves et al. in press). The "100% heritage" approach (Pottgiesser 2019; Roders 2019; Roders and Pottgiesser 2020), "where resources are, by rule, to be conserved as part of a broader ecosystem" (Roders 2018) demands clearer definitions of what matters (attributes) and why it should be preserved (values). Having such clearer definitions requires effective significance assessments that are able to provide information on a broader scope of values and attributes than the traditional historic and aesthetic values (Veldpaus 2015). A concise framework to assess the sustainability of heritage buildings could be a useful tool to inform decision-making and to ensure that future impact assessments of the conservation of heritage buildings has a baseline for comparison.

In the last two decades, several methods have been developed to assess buildings' sustainability. Some market-oriented certification systems, such as BREEAM (Building Research Establishment Environmental Assessment Method), have been adapted to cover existing buildings and favouring building reuse and compact development (Balson, Summerson, and Thorne 2014). However, as found by Appendino (2019), current sustainability certification systems and urban assessment tools consider heritage indicators only in a partial and shallow way. Since building codes and regulations are mostly developed for new buildings or major renovations, they do not reflect the specific features of ancient buildings (Ornelas et al. 2020). Additionally, voluntary certification systems of sustainable performance, even if applicable to existing buildings, do not embrace the full complexity of heritage conservation (Boarin et al. 2014). Despite being a central aspect for sustainable development, according to international standards (ISO 2011), culture-related indicators are rarely mentioned in general building assessment tools, such as BREEAM, LEED (Leadership in Energy and Environmental Design) or SBTool (Sustainable Building Tool) as evidenced by da Silva and Ramos (2010). The LBC (Living Building Challenge) assessment framework, even if not specifically developed for heritage buildings, can also be applied to them to determine the impact of conservation projects (Living Future Institute 2019), since requirements can be adapted to the context, as long as the main goals remain constant.

With a more theoretical approach, some methods have been developed to assess the sustainability of heritage buildings, often based on the set of indicators of the market-oriented certification systems. In a study,

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Shetabi (2015) selected indicators from the LEED rating system that were proven suitable to assess heritage buildings, to include environmental indicators in significance assessments. Similarly, the GBC Historic Buildings (Boarin, Guglielmino, and Zuppiroli 2014) added a new category — Historic Value — to the existing LEED ones. The goal of the GBC Historic Buildings is not to select sustainability indicators for heritage buildings, but to ensure that the assessment of conservation projects in historic contexts includes criteria linked to historical and cultural aspects. In another study, da Silva and Ramos (2010) combined indicators from BREEAM, LEED and SBTool, to obtain a more comprehensive set of indicators for built heritage.

The current literature shows that tools to assess the sustainability of heritage buildings are essential to support decision-making at the policy level and to implement sustainability objectives in the management of heritage properties (Leus and Verhelst 2018; Ornelas et al. 2020). Such tools can also be used to assess the sustainability of conservation projects of heritage buildings, taking into consideration the protection of historic and cultural values (Boarin, Guglielmino, and Zuppiroli 2014). For example, the GBC Historic Buildings framework (Lucchi, Boarin, and Zuppiroli 2016) requires a preliminary baseline report on the condition of the building, based on the principle that the historic building performance must be assessed according to a reference condition rather than to normative performance levels (Boarin et al. 2014). However, the framework does not establish guidelines or indicators that allow measuring this reference condition, contrary to other frameworks and sets of indicators (da Silva and Ramos 2010; Havinga, Colenbrander, and Schellen 2019; Shetabi 2015).

Appendino (2018) concluded that the existing sets of indicators for built heritage "are still far from offering a holistic measurement of the advantages of heritage on an environmental, economic and social level". Also, Ornelas et al. (2020) stated that current methods are partial and do not offer an integrative approach to the different issues involved in heritage conservation. On the one hand, according to Havinga (2019), most literature on heritage refurbishment does not include the systematic evaluation of heritage values. On the other hand, Shetabi (2015) concluded that sustainability indicators are missing in the significance assessment of heritage buildings. According to Correia et al. (2013), although there are different multicriteria approaches for heritage buildings, there is still a gap in the integration of different sustainability aspects in terms of their significance assessment, since most of the studies focus on the quantitative aspects, such as the hygrometric performance. However, most frameworks proposed by the aforementioned authors are not comprehensive enough. The set of indicators developed by Shetabi (2015) solely focus on environmental issues, while the framework proposed by Havinga (2019) assesses valuable attributes to establish limits of change for future interventions, but does not include environmental indicators. In Ornelas' (2020) framework — covering resident perceptions, safety and degradation, and valuable attributes of the building — the environmental indicators are absent.

As such, the literature shows that general methods for building' sustainability assessment do not sufficiently cover the complexity of heritage conservation (Boarin et al. 2014). Specific methods developed to assess heritage buildings lack a balanced integration of environmental and cultural issues that are an essential part of sustainable conservation processes (Correia et al. 2013).

While an assessment framework for the sustainable conservation of built heritage is useful to support significance assessments and design-related decisions in conservation projects, it requires a concise set of indicators, with sufficient coverage of the central aspects of sustainability (ISO 2011) and heritage values, so as to set the analysis of existing buildings. Such set of indicators shall enable: the measurement of the value of heritage buildings in the scope of the sustainable development (Shetabi 2015); the definition of limits of acceptable change (Havinga, Colenbrander, and Schellen 2019); and the identification of aspects that can be improved in the intervention (da Silva and Ramos 2010). The set of indicators shall provide a common language to be used between stakeholders (Leus and Verhelst 2018) and ensure that intervention assessments are carried out in relative terms by comparing the building's performance with its initial situation (Boarin, Guglielmino, and Zuppiroli 2014; da Silva and Ramos 2010).

This paper presents a theoretical analysis of existing assessment frameworks aiming at identifying common indicators and priorities for the sustainable conservation of built heritage. It aims at compiling a core set of indicators, simple to use and understand, that allow quantification, simplification, and communication (ISO 2011) of decisions in conservation processes.

2. Materials and methods

This study is comprised of two parts (Figure 1): in the first part, the indicators of the VerSus framework and the Living Building Challenge (LBC) are compared, extracting the first set of indicators. In the second part, this set of indicators are analysed according to key

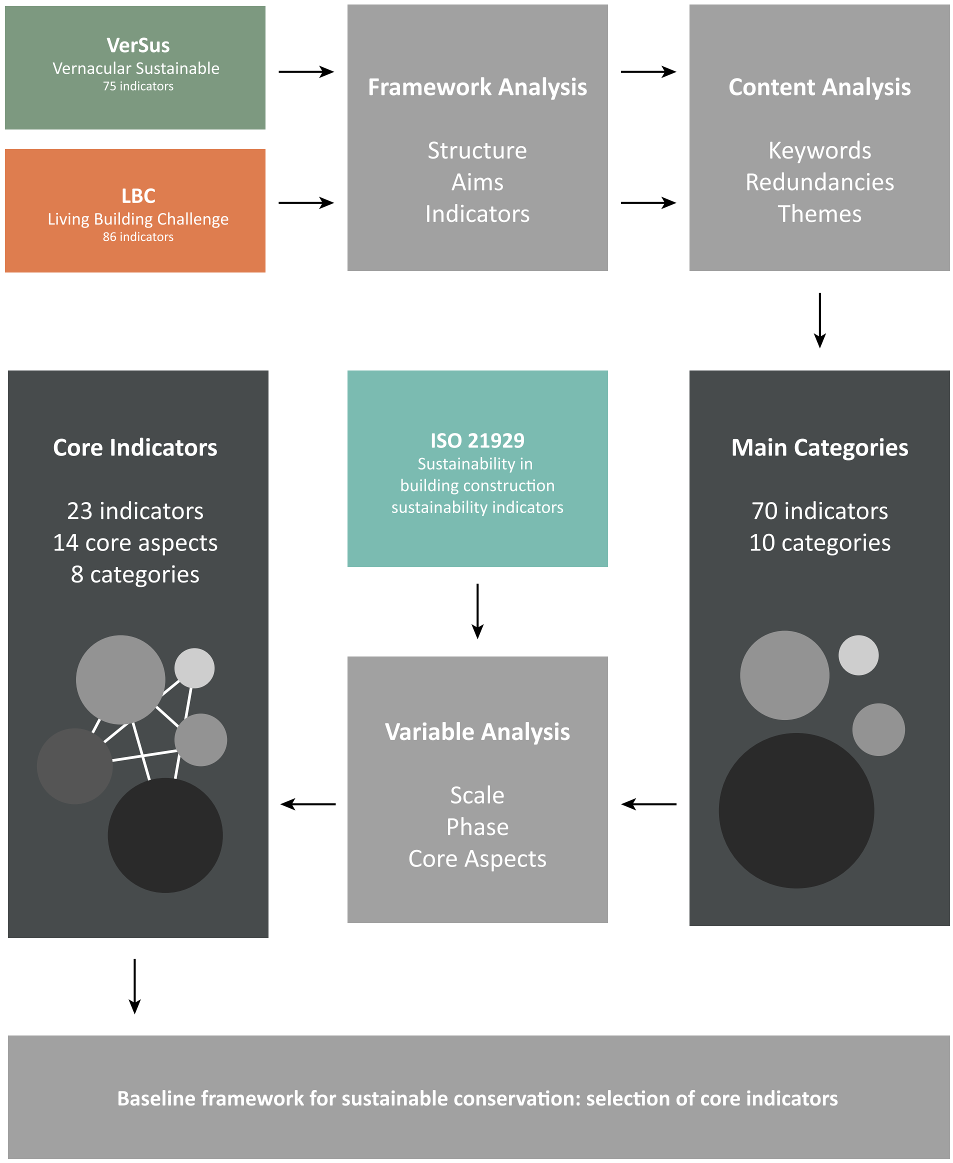

Figure 1. Diagram of the study design.

variables identified in the ISO Standard 21929 on "Indicators for Sustainability in Building Construction" (ISO 2011). These two parts allow to identify priority indicators, eliminate redundancies, and filter the indicators that apply to existing buildings, while covering the fundamental aspects of sustainable development

2.1. Comparative analysis of two methods

This research integrated indicators from two types of frameworks: 1) general methods for building sustainability assessment and, 2) specific methods for heritage buildings. Figure 2 presents the criteria for the selection of the two methods analysed, including the coverage of cultural values and environmental indicators, the scope, and the scale.

In the group referring to general methods, the Living Building Challenge (LBC) framework was chosen, because of the integration of indicators that cover cultural, social, historic, aesthetic and ecological values of the Built Heritage, under the category "Beauty and Inspiration" (Living Future Institute 2019). The LBC is originally designed for the assessment of buildings in the operation phase. For this reason, most of the indicators can be used to assess the current condition of existing buildings before the intervention. This choice also allows extending the comparison of indicators and categories to a methodology not previously addressed in the scope of Built Heritage (Boarin, Guglielmino, and Zuppiroli 2014; Shetabi 2015) and to overcome the limitation of indicators related to cultural issues, already identified by da Silva and Ramos (2010). In the Heritage-specific methods, VerSus was

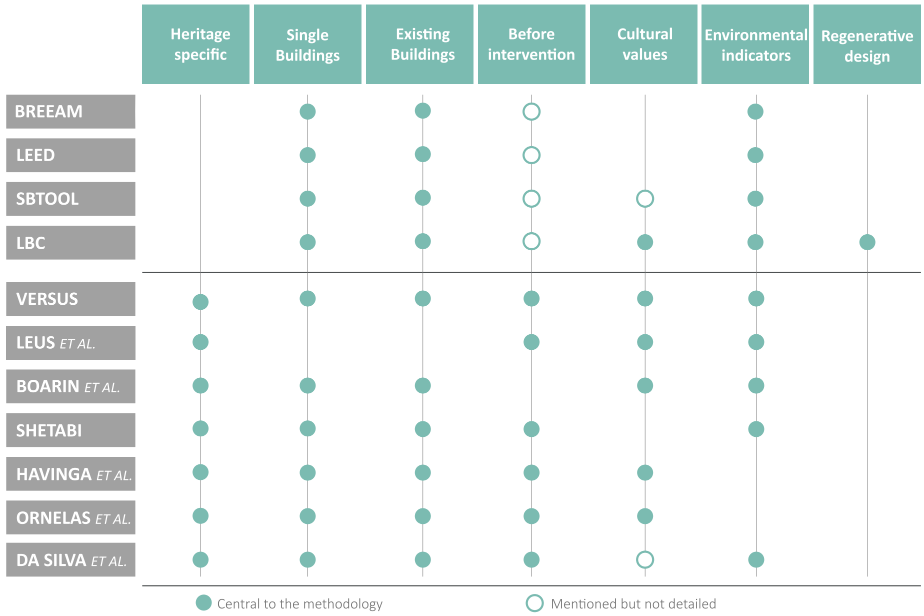

Figure 2. Criteria for the selection of the methods to analyse.

chosen, since it proposes a holistic understanding of sustainability, covering tangible and intangible aspects of the social, environmental and economic dimensions (Correia, Dipasquale, and Mecca 2015).

In the selection of the methods to analyse, the authors tried to ensure enough range of diversity, by covering different approaches. In this way, it was possible to select methods that have the following characteristics:

They are at the same time theoretical frameworks and market certification tools;

They are focused on general buildings and specifically on heritage buildings;

They are based on qualitative and quantitative assessment processes;

They are based on prescriptive or performance-based approaches;

They have the goal of sustainable or regenerative design.

The two chosen methods have in common the following properties:

Spatial scale: applicable to single-buildings;

Temporal scale: focusing on existing buildings;

Results: descriptive/informative results.

In the first part of the study, a framework analysis was performed, to identify differences and similarities between the structure and terminologies of the two methods. That allowed to clarify redundancies and identify repeated indicators. This processapplied an inductive content analysis, by identifying keywords that allow to cluster indicators in common categories according to the intent or with the issue tackled. Affinity diagramming was used to synthesize findings and identify general trends (Martin and Hanington 2012).

2.2. *Classification of the indicators*

The selected indicators were classified according to three variables specified in the ISO 21929 (ISO 2011). The first two variables are related to the type of indicators: the scale of analysis and the life-cycle phase. For the final set of indicators, only the ones applicable to existing buildings were selected — excluding design phase, new buildings, and operation phase. Concerning the scale, this study is limited to indicators directly related to the building. For that reason, only indicators focused on the building and the building-plot are considered, excluding those related to location and processes.

The third variable considered in this research is related to the scope, ensuring that the selected indicators cover all the core aspects considered "essential from the viewpoint of assessing the contribution of a building to sustainability" (ISO 2011). Being the primary goal of this research to establish a concise set of indicators, only the ones aligned with the core aspects defined by the ISO 21929 are included in the final set of indicators. The remaining indicators were excluded, even if potentially relevant to the assessment of existing buildings.

3. Background

3.1. VerSus and Living Building Challenge

The two methodologies, VerSus and Living Building Challenge (LBC) differ but do share a focus on single buildings (scale) and on a range of life cycle phases, from design to operation (see Table 1).

The VerSus methodology is the result of a European research project developed between 2012 and 2014 by a European network of academic institutions. The project aimed at "creating a reliable technical tool with a high dissemination potential" (Correia, Dipasquale, and Mecca 2015) to raise awareness of the value of vernacular heritage for sustainability. That research project identified strategies of integration of vernacular heritage to the natural and socio-economic environment in several case studies across the world (Correia, Dipasquale, and Mecca 2015). The identified strategies were then systematized into low-technology principles to be integrated into contemporary architecture. An operative approach was developed as an "instrument to assess the sustainability of building interventions", through a set of guidelines to evaluate the existing situation and provide information to plan future interventions.

The Living Building Challenge (LBC) is a commercial international building certification method applied in more than 25 countries worldwide. It was initially launched in 2006 by Cascadia Green Building Council (GBC) — a coalition between the Canada and US Green Building Councils. The idea behind the LBC was to improve the LEED rating system (from the US GBC) by moving "beyond merely being less bad and to become truly regenerative" (Living Future Institute 2019). Regenerative design is an emerging concept defined by Cole (2012) as a method that emphasises "a co-evolutionary, partnered relationship between humans and the natural environment". This definition connects with that of sustainable conservation (Gonçalves, Mateus, and Silvestre 2019), as heritage is a co-evolutionary process of the environment, made of intangible, tangible and natural aspects. One of the main differences with other certification tools, such as LEED or BREEAM, is that LBC's indicators are entirely focused on existing buildings and the assessment is based on the actual performance.

Table 1. Factsheets on VerSus and of the LBC.

	VerSus	LBC
Title	Vernacular Heritage Sustainable Architecture	Living Building Challenge
Author	VerSus	Living Future Institute
Year	2012–2014	2006–2019
Context	European research project	International building certification system
Target	Vernacular heritage	Buildings in operation
Aim	Eco-responsible architecture	Regenerative design
Approach	Prescriptive	Performance-oriented
Process	Qualitative	Quantitative
Scale	Single-buildings	Single-buildings
Phase	From design to operation	From design to operation

3.2. ISO 21929: sustainability in building construction — sustainability indicators

The ISO 21929 standard defines principles for sustainability in building construction and establishes guidelines for the development of sustainability indicators within a common framework, allowing for transparency and comparability. According to the aims of development and application, indicators can be classified in eight types: the object of assessment; stage of the life cycle; type of information; degree of influence; complexity; assessment process; spatial boundaries; and temporal boundaries (ISO 2011). In the scope of the present research, only the object of assessment and stage of the life cycle were considered for the classification.

The object of assessment is related to the scale of the indicator. Indicators can be related to location, site, building or processes. The location differs from the site over its broadness: the former refers to the neighbourhood in an urban or regional scale while the latter refers to the immediate surroundings of the building and to the physical land where it was built. Process-related indicators include management, operation, and procurement indicators that, by their dependence upon the stakeholders involved in the processes, are dynamic by nature. Indicators can also be classified according to the life stage, as typically for new buildings, for existing buildings or the operation stage (ISO 2011). Commonly, indicators related to the operation stage are process-related.

For sustainable development, seven areas of protection against potential impacts of the building sector are defined in the ISO 21929, namely: ecosystem, natural resources, health and well-being, social equity, cultural heritage, economic prosperity, and economic capital. These areas of protection can be affected by several aspects of a building, demonstrating the multi-effect of indicators and their interdependence for the three sustainability dimensions. Considering this factor, the standard establishes a set of priorities — core areas of performance — for building assessment, that are directly related to the core areas of protection (ISO 2011):

Emissions to air: global warming and ozone depletion potential, considering embodied energy and energy flows;

Use of non-renewable resources: the amount of non-renewable resources used, including extraction and disposal of natural resources and reuse of materials, and energy consumption and efficiency;

Freshwater consumption: use and onsite management of water;

Waste generation: the amount of waste produced by demolition and avoided by reuse, recycling and maintenance;

Change of land use: choice of place, avoid construction in greenfield and redevelopment of existing built environment;

Access to services: urban density and proximity; open spaces accessible to the public and access to public transportation and essential services;

Accessibility: equitable access for users, including with physical disabilities;

Indoor conditions and air quality: considering thermal, visual, and acoustic conditions and air quality;

Adaptability: flexibility for change of use according to new needs and resilience to climate change;

Costs: life cycle costs, considering initial cost, operation, maintenance, and end-of-life costs;

Maintainability: quality of the building and durability, scale, and timing of maintenance measures;

Safety: including structural stability, resistance to weather, and safety in use;

Serviceability: functionality of the building and ability to fulfil user requirements;

Aesthetic quality: integration with surroundings, impact on the cultural value of the site, architectural quality, and attractiveness.

According to the ISO standard, a framework of core indicators must consist of indicators that represent all of the 14 aspects and they must be related to one or more core areas of protection. Assuming that this does not result in a sufficiently comprehensive list of indicators and hence additional indicators may be needed according to each specific case. Additionally, the standard identifies some secondary aspects that may be considered in more detailed frameworks, including the use of renewable resources, ecological quality of the site, nuisance to the neighbourhood, and community participation (ISO 2011).

4. Results

4.1. Comparative analysis

4.1.1. Structure

Versus and LBC share the aim of improving the sustainability of existing buildings and both follow a similar sequence (see Figure 3). The VerSus framework follows a structure based on the three dimensions of sustainability — environmental, social, and economic. The environmental dimension deals with the impacts on the environment; the socio-cultural dimension relates to the community and to the sense of belonging and is "more linked to the processes than to the physic reality

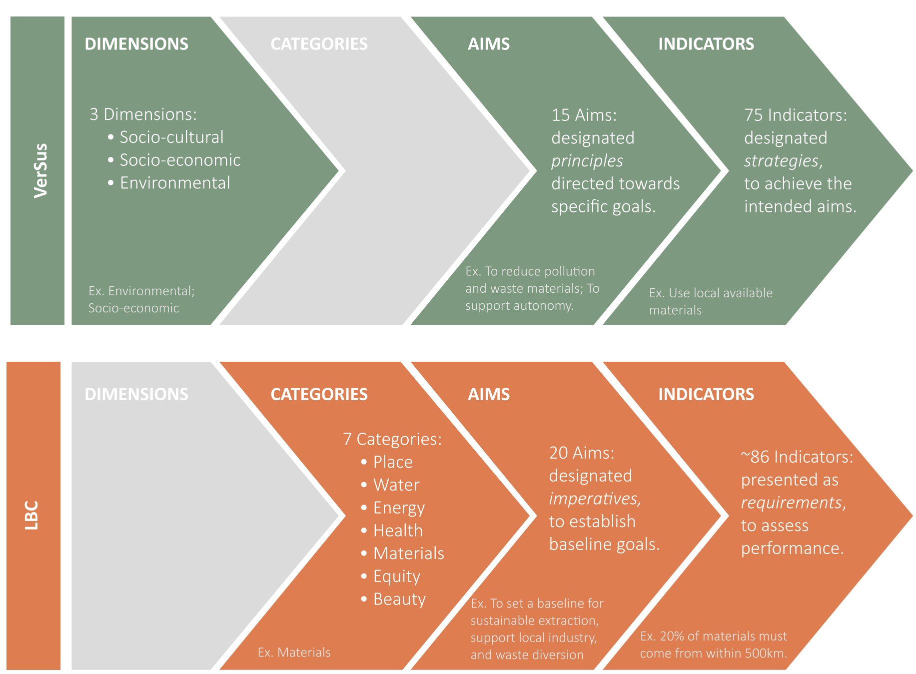

Figure 3. Structure flow and terminology of VerSus and LBC.

itself" (Correia, Dipasquale, and Mecca 2015); and the socio-economic dimension, in which the idea of cost is related to the concept of effort, which is considered a more suitable approach in the context of vernacular heritage. The three sustainability dimensions are then subdivided in fifteen (15) principles that describe the goals towards sustainability. Furthermore, each principle is subdivided into a set of strategies: the indicators that define if a certain principle is being addressed. In total, the VerSus framework is composed of seventy-five (75) strategies, organised in fifteen (15) principles and three (3) sustainability scopes.

The LBC framework is organised in seven performance areas: place, water, energy, health and happiness, materials, equity, and beauty. The framework uses the metaphor of the flower, designating each performance area as a "Petal" that contributes to the whole. Each Petal is subdivided into twenty (20)"imperatives" (equivalent to the principles in VerSus) that establish specific baseline goals for every project. Within each imperative, some requirements or parameters are established to assess the performance. Since not all the parameters are mandatory, the total number is flexible but tends to amount eighty-six (86). The following definitions were inferred from the analysis of the structure of the two methods:

Sustainability Dimensions: refer to the three pillars of sustainable development as defined in the Brundtland Report (WCED 1987) and includes the economic, the social and the environmental dimension;

Categories: constitute the main organising themes of the indicators according to their scope and area of influence;

Aims: or principles or imperatives, establish fundamental rules towards sustainability goals to achieve by the building;

Indicators: or strategies or requirements, establish the criteria to assess the performance of the building concerning each aim.

This common structure and terminology allowed identifying their common priorities, even when using different terminology. For example, the indicator concerning the use of local resources is common to both methodologies, aiming at reducing pollution and waste, but also at supporting local industry (LBC) and autonomy (VerSus).

The following example illustrates the differences in assessment processes, which is primarily qualitative with VerSus and quantitative with LBC. The same indicator can be assessed with a single "yes/no" question (VerSus) or quantified according to established numerical criteria (LBC). The indicator "*using local materials*" in VerSus, is assessed in LBC as "*living economy sourcing*", which establishes the following detailed parameters: "*20% of materials within 500 km", "30% of materials within 1000 km", "25% of materials within 5000 km*". Thus, the LBC framework allows to differentiate between the level of performance by establishing different grades for each indicator — the use of local materials.

In the VerSus framework, the categorisation under sustainability dimensions leads to the double-counting of indicators that can influence different dimensions simultaneously, like the environmental and socio-economical dimensions, for example. In the LBC, the aggregation of indicators within categories that crosscut the three dimensions of sustainability evidences a holistic approach that considers the multi-effect of indicators, avoiding redundancies.

The aim of this comparative analysis of the structure of the frameworks is to identify and eliminate the "double counting" of indicators in each framework so as to reach a narrower set. The process allowed to reduce the initial set of indicators from 161 (75 indicators from VerSus and 86 indicators from LBC) to a set of 109 indicators (52 indicators from VerSus and 57 indicators from LBC).

4.1.2. Main categories

In the first phase of the content analysis, 20 sustainability themes were deduced from the pool of indicators: site, indoor pollution, indoor comfort, water, energy, building scale, building techniques, carbon footprint, waste reduction, materials, resilience, maintenance, transportation, production, certification, collective welfare, community engagement, ecological values, tangible values and spiritual values. These themes were then clustered into groups, considering the affinity of the problems approached in the indicators This process resulted in 10 main categories, defined as follows:

Site: land management according to ecological site features;

Energy: reduction of consumption and onsite production;

Water: reduction of use and onsite management;

Construction: building scale, techniques and solutions;

Materials: sources, embodied energy, reuse and recycle, waste diversion;

Indoor environment: avoid pollution sources and ensure a comfortable indoor environment;

Durability: strategies for maintenance and resilience to extend building lifetime;

Processes: not directly related to the building, but related to the construction and operation, such as food production or transportation;

Community: related to community welfare — including physical features of the environment, and with community engagement and inclusion;

Values: cultural identity, the spirit of the place and connection with nature.

The alluvial diagram in Figure 4 shows how the indicators of the two methodologies were clustered in the main categories. By following the connections on each side of the diagram, it is possible to identify the indicators that are repeated, or that are very similar in scope in the two methods. For instance, in the indoor environment category, LBC includes the indicator "*views outside and daylight*", while the VerSus proposes "*natural light and sun radiation*" in the commonly occupied spaces. In these situations, where the scope of the indicators was found redundant, the indicators were merged.

When researching the relationship of the indicators in each framework with the main categories, the most important difference found was the implicit weighting of the indicators towards the overall assessment of sustainability. In both methods, there are no explicit weights applied to each indicator, and the importance of the categories is determined by the number of indicators used for the overall assessment. By directly targeting heritage buildings, the VerSus tool considers more indicators related to cultural values than the LBC tool does. Hence, for example, passive solutions, at the building and building techniques scales, are more emphasised in VerSus. Similarly, in LBC there is more weight given to the responsible sourcing of materials or to the onsite production of energy.

A few "umbrella indicators", due to their broad description, allowed to cover two or more detailed indicators. In these cases, only the broader indicator was kept. Accordingly, the indicator "*reduce embodied carbon*", was kept as an umbrella indicator that considers, as sub-indicators, "*reduce embodied carbon in structural materials*" and "*use indoor materials with low carbon footprint*". From this stage of the analysis, after clearing double-counting, redundancies, and sub-indicators, the original set of indicators was reduced to seventy (70), which were subsequently classified according to the ISO 21929 (ISO 2011).

4.2. Classification of indicators

4.2.1. Object of assessment

The chart in Figure 5 presents the distribution of indicators according to the category and object of assessment. From the set of 70 indicators previously selected, only a small percentage refers to location-related indicators (such as "*facilitate public transportation*"). Almost a third (34%) of the indicators is related to dynamic processes, which are not directly measurable in the building or in the site (such as "*enhance community engagement and participation*" or "*purify water without using chemicals*").

The set of indicators that results from this classification includes thirty-seven (37) indicators, exclusively focused on the assessment of the building and to its immediate surroundings. The remaining indicators were excluded from the next steps of the analysis.

4.2.2. Life cycle stages

Most of the indicators previously selected proved to be technically adequate to assess both new and existing buildings, even if in some cases, upon application, some may not be considered relevant to assess the significance of heritage buildings. The indicators related to the operation phase are always connected to dynamic processes and were previously excluded in the classification by the object of assessment.

The diagram in Figure 6 summarises the set of indicators that apply to existing buildings and that can be assessed at the building and site scale, organised according to the categories that emerged in the analysis. Considering the life cycle stage and the object of assessment, the category "processes" previously identified was removed. Only three (3) indicators remained in the category "durability", that could be thematically integrated within other existing categories, without losing their focus. As such, the indicator "*onsite water storage*" was included in the category "water"; the indicator "*energy autonomy for emergencies*" was included in "energy"; and the indicator "*strong and durable building systems*" was included in "construction". After this process of selection, 34 indicators organized in 8 categories, were classified according to the core aspects of sustainable development (ISO 2011).

4.2.3. Core aspects of sustainable development

Both the core areas of protection and the core aspects that affect those areas of protection can be related to the categories deduced by the content analysis in section 4.1. However, this relation is not always direct, since sometimes the categories can cover more than one aspect or area of protection. For instance, while the category "water" can be immediately related to aspects such as freshwater consumption, or the indoor quality with indoor conditions and air quality, other categories, such as energy or materials, can cover aspects related to emissions to air, use of non-renewable resources, waste generation and costs. For this reason, in this phase of the analysis, the indicators were disaggregated from the previous categories and analysed individually.

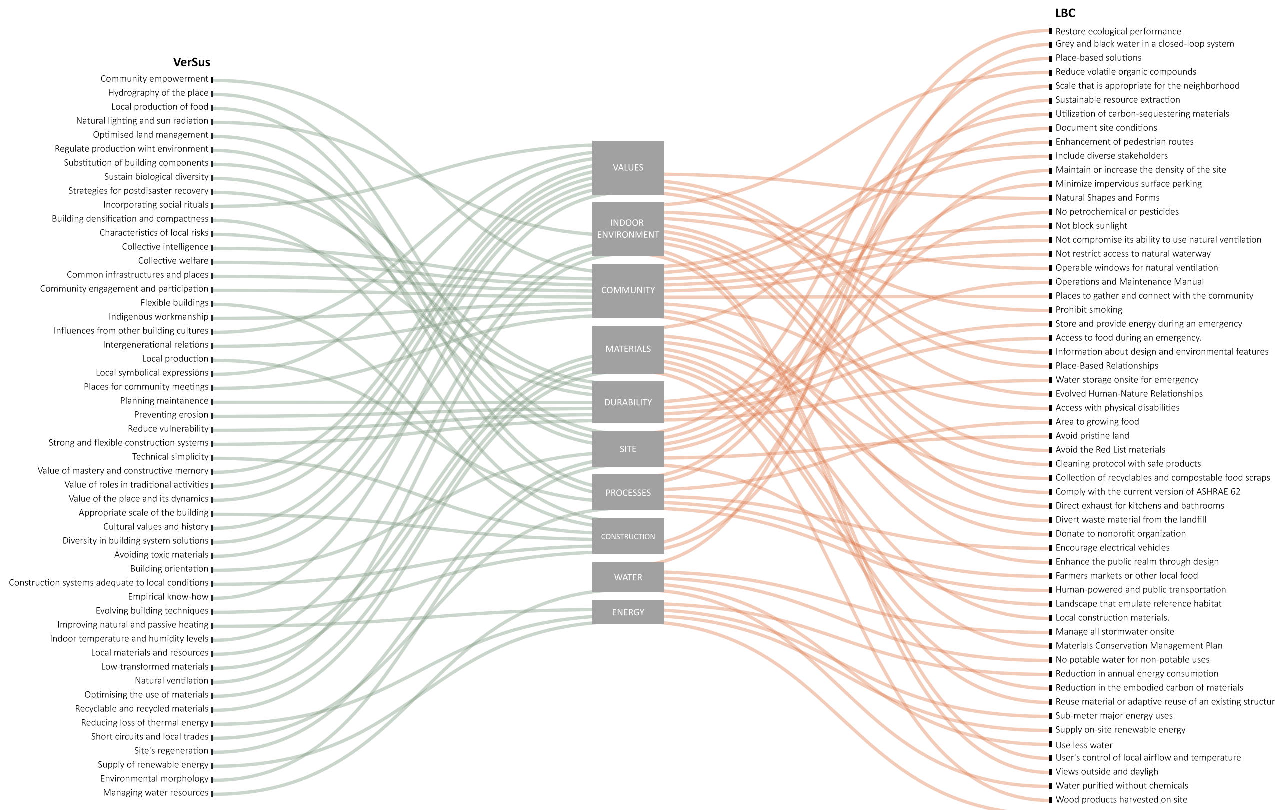

Figure 4. Alluvial diagram with the identification of common themes in VerSus and LBC.

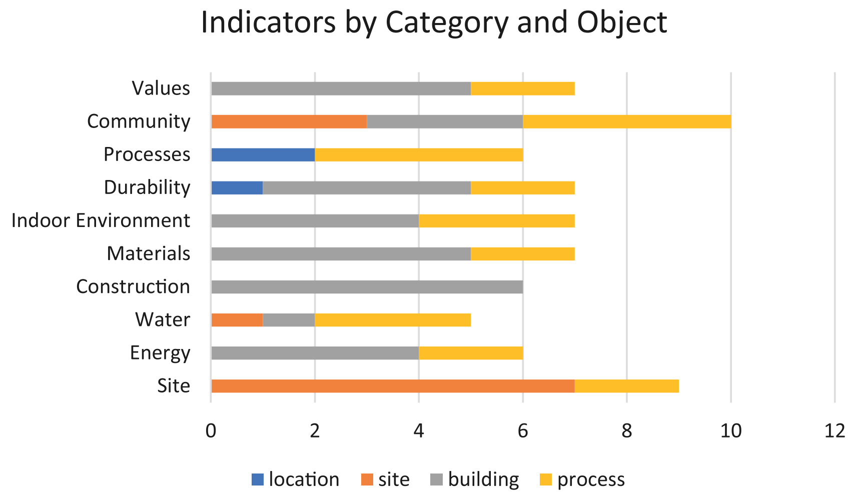

Figure 5. Number of indicators by category and object of assessment.

The diagram in Figure 7 shows the distribution of the indicators according to the core aspects as defined by the ISO 21929. The indicators were kept when they provide useful information about the performance of the building, even if they did not perfectly match the indicators recommended by the ISO. Indicators related to secondary aspects or not mentioned in the standard were excluded. The core set of indicators resulting from this analysis consists of 23 indicators.

The indicators "*mastery and construction memory*", "*place-based relationships*", and "*environmental features*" — related with values — were included because of their relationship to the aesthetical quality as further defined in the ISO 21929: "integration and harmony of the building with the surroundings; impact on the cultural value of a site, neighbourhood, local heritage and built environment" (ISO 2011). The indicator of "*mastery and construction memory*" is related to the cultural and heritage significance of the site. The indicators "*place-based relationships*" and "*environmental features*" reflect the integration of the building with the surroundings, covering both tangible (colour, materials, views, light, space) and intangible (geographic, historic, cultural, ecological connections with the spirit of the place) dimensions of this relationship (Kellert, Heerwagen, and Mador 2011).

4.3. Set of core indicators for sustainable conservation

The results of the analysis show that the organisation of the indicators according to the sustainability dimensions (social, economic, environmental) is not suitable for a holistic framework that aims at integrating such dimensions (ISO 2011). By using an approach where indicators are categorised according to the three dimensions of sustainability, the VerSus framework promotes the double-counting of indicators. The organisation of indicators according to the core aspects as suggested by the ISO 21929 increases the complexity of the analysis, since most of the indicators can be related to more than one aspect. However, while this system of organisation is oriented towards the outcomes, the approach of the LBC framework — distributing indicators according to main categories — proves to be clearer and more effective to avoid redundancies. As such, the set of indicators for the assessment of sustainable conservation of heritage buildings proposed in this research were reorganized according to the categories that emerged in the content analysis. This option allows merging the operative approach of the LBC framework with the inputs on priorities deduced from the combination with the VerSus framework.

The resulting set of twenty-three (23) core indicators, presented in Table 2, considers indicators that cover the essential principles of sustainable development, according to the international standard (ISO 2011). By excluding indicators related to design and operation stages, and by focusing only on identifiable features in existing buildings, this set of indicators is adequate to a baseline survey of heritage buildings before conservation interventions. The focus on indicators at the single-building scale, make it adequate to identify sustainable values that can be addressed in the design stage, supporting decisions related to elements to preserve, change or remove, according to their sustainability value.

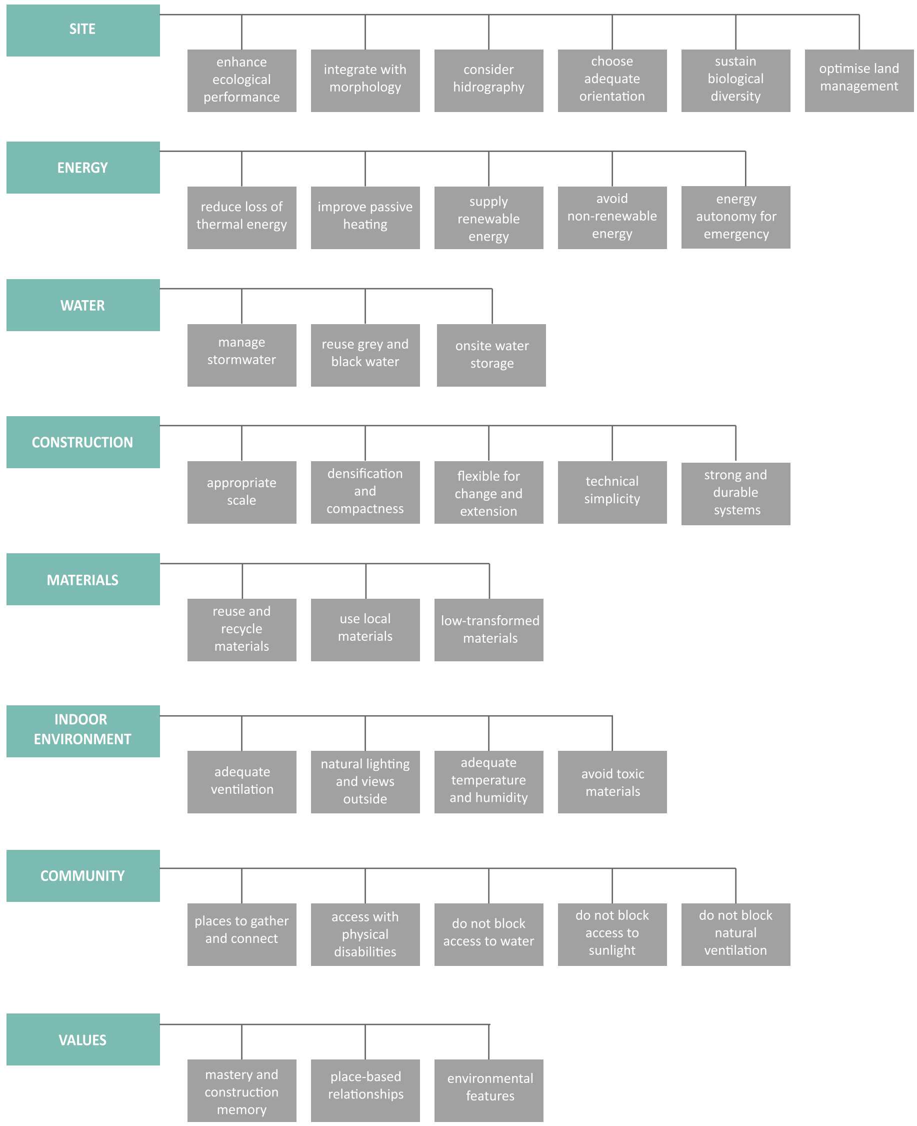

Figure 6. Indicators that apply to existing single-buildings divided by category.

5. Discussion

The complex interdependencies between social, environmental, and economic dimensions of sustainability must be taken into account when developing a set of indicators for sustainability assessment (ISO 2011). The VerSus methodology proposes a holistic approach to sustainability and ensures that the three dimensions of sustainability are considered in the study of objective architectural indicators (Correia et al. 2013). However, by explicitly distributing indicators in the three dimensions, it loses the opportunity for deeper integration of the three pillars of sustainability, while increasing the double-counting of indicators. This is the case, for example, with the indicator "*use of local materials*" that is addressed both in the economic dimension and in the environmental dimension. This proves the multi-effect of the indicator, but also increases the complexity of the assessment, since the data could be collected only once and considered in a holistic perspective for its contribution to sustainability. The set of indicators developed by Leus (2018), starts from the three dimensions of sustainability — social (people), planet (environment), and economic (profit) — and adds to them the dimensions policy and patrimony, related with planning and legal constraints, and with heritage significance, respectively. This mixed approach in the organisation of the indicators — between the sustainability dimensions and the performance areas -, does not seem to solve the problem

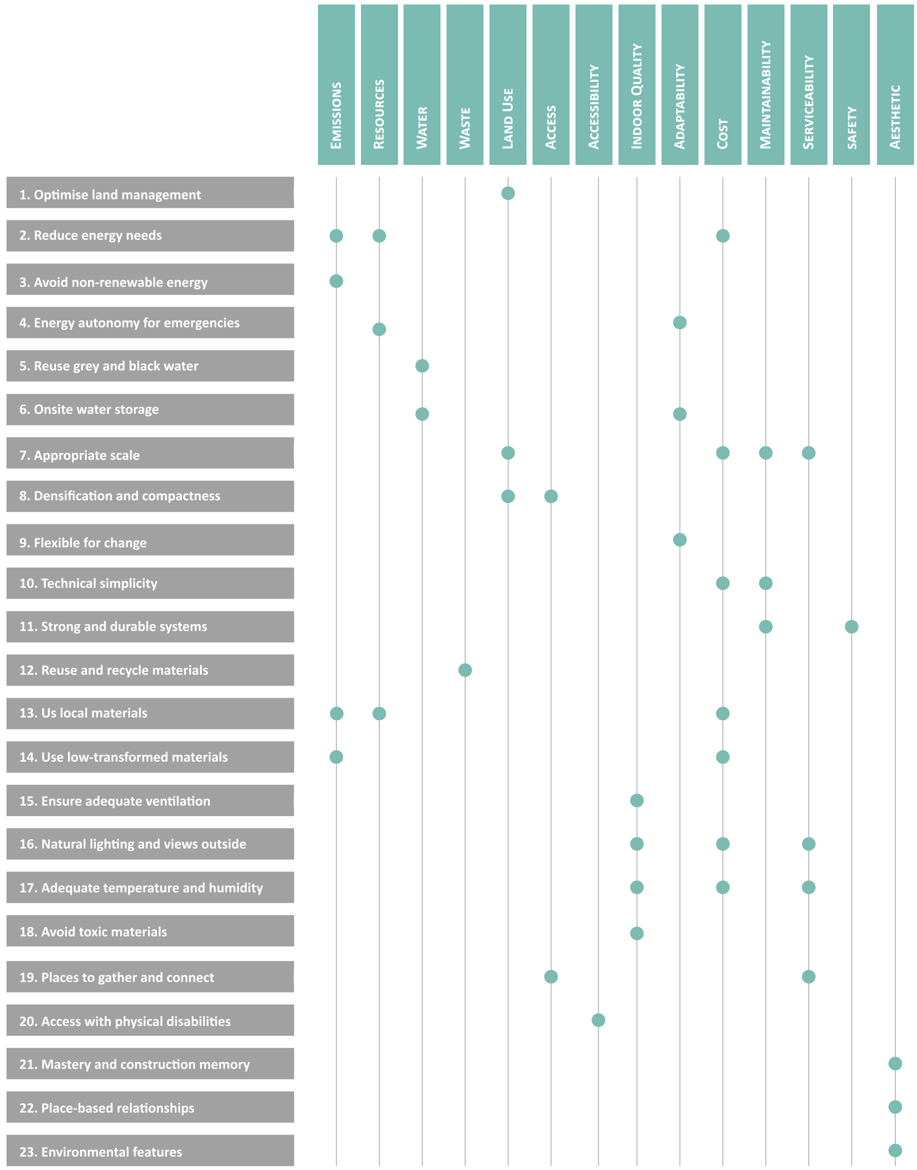

Figure 7. Distribution of indicators according to core aspects of sustainability.

identified in the VerSus framework, since some aspects measured by the indicators affect more than one dimension.

The approach of the LBC framework, organising indicators in key areas of performance, seems to be more effective at avoiding the double-counting of indicators while proving the interdependency of the three dimensions of sustainability. Also, the set of indicators developed by Shetabi (2015)(based on the LEED assessment system), and the one developed by da Silva and Ramos (2010) (merging BREEAM, LEED and SBTool) structure the indicators according to categories. Despite the different approaches, structures, and objects of assessment of the two tools analysed, their indicators can be clustered in similar categories. da Silva and Ramos (2010) proposes a set of 50 indicators, organised in 9 categories: place, transport, water, energy, materials, emissions, indoor environment, use, and cultural, economic, and social aspects. The set of 45 indicators developed by Shetabi (2015) are organised in 6 categories: site and location, urban setting and linkages, water efficiency, energy and resources, envelope and fabric, and indoor environmental quality.

Figure 8 illustrates the categories that emerged in the present research in comparison to the sets of indicators developed by da Silva and Ramos (2010) and Shetabi (2015), confirming the existence of cross-cutting priorities for sustainable development, not only in the two

Table 2. Set of indicators for the assessment for sustainable conservation of heritage buildings.

SITE
(1) Optimise land management
ENERGY
(1) Reduce energy needs
(1) Avoid non-renewable energy sources
(1) Ensure energy autonomy in emergency
WATER
(1) Treat and reuse grey and black water onsite
(1) Ensure water storage onsite
CONSTRUCTION
(1) Assure appropriate scale of the building
(1) Promote building densification and compactness
(1) Flexible for possible changes and extensions
(1) Enhance technical simplicity in building processes
(1) Use strong and durable construction systems
MATERIALS
(1) Reuse and recycle materials
(1) Use locally sourced materials
(1) Use low-transformed materials with low embodied carbon
INDOOR ENVIRONMENT
(1) Ensure adequate ventilation
(1) Guarantee proper natural lighting, sun radiation and views outside
(1) Ensure adequate levels of indoor temperature and humidity
(1) Avoid toxic materials
COMMUNITY
(1) Provide places for occupants to gather and connect with the community.
(1) Safeguard access for those with physical disabilities
VALUES
(1) Value of mastery and construction memory
(1) Connected to place and culture through place-based relationships
(1) Incorporate environmental features, light and space, and natural shapes and forms

methods analysed (LBC and VerSus) but also in other BSA tools. Site, energy, water, materials, and indoor environment are common key areas of performance. Transport and urban setting were excluded from this research for being outside the boundaries of single buildings. The remaining categories, even if with different aggregation and designations, also cover common issues, such as emissions and construction.

In the framework developed by Shetabi (2015), the indicators related to materials and construction are merged in the category "*envelope and fabric*". The same approach, organising the assessment according to building attributes or components, is used by Ornelas et al. (2020). This option points out to an important possibility for future research to structure indicators according to building attributes for a more intuitive approach during the building survey. It would also allow to immediately relate the sustainability performance with the value of each attribute of the building, establishing priorities for intervention and limits of acceptable change, as suggested by Havinga (2019).

To use the set of indicators for an efficient evaluation, it is also important to consider both the clear phrasing of indicators and the desired methodological approach — qualitative or quantitative. In this aspect, lessons can be learned from both VerSus and LBC frameworks. On the one hand, in the VerSus framework, indicators are formulated in a layman's language, easily understandable and sufficiently open to be applicable in different buildings and contexts (depending on scale, age, state of conservation, typology, classification, or budget). As an example, the indicator "*ensuring adequate ventilation*" allows the result to be measured, observed, simulated or deduced; the equivalent indicator in the LBC framework "*Sufficient operable windows to provide natural ventilation for at least six months of the year*", limits the evaluation to a certain attribute — windows — excluding the potential of vernacular ventilation systems that could be found in heritage buildings, and implies measuring and monitoring the performance during the occupation stage — not feasible or relevant in vacant buildings, for instance. On the other hand, the LBC framework provides more detailed parameters that are useful to guide the evaluation process and detail levels of performance, contributing to more objective results. As an example, the already mentioned indicator on the use of local

Da Silva & Ramos (2010)	Shetabi (2015)	Current study
sustainable place	site and location	site
sustainable transport	urban setting and linkage	
resources- water	water efficiency	water
resources- energy	energy and resources	energy
environment- emissions	envelope and fabric	materials
resources- materials		construction
interior environment	indoor environmental quality	indoor environment
sustainability in the use		community
cultural, economic, social		values

Figure 8. Comparison of the main categories of indicators with da Silva and Ramos (2010) and Shetabi (2015).

resources is subdivided in several parameters (*20% of materials within 500 km, 30% of materials within 1000 km, 25% of materials within 5000 km*) to allow presenting the results in a scale of intervals, such as a Likert scale, as proposed by Ornelas et al. (2020). That would allow each indicator to provide a complete evaluation result, concerning its value to sustainability, and compare the performance of different buildings, solutions, or interventions.

The set of indicators proposed in the present research is limited to twenty-three (23) indicators, significantly fewer than other sets developed for heritage buildings. da Silva and Ramos (2010) developed a set comprising fifty (50) indicators. Itincludes indicators that exceed the core aspects defined in the ISO (e.g., renewable resources, water management, etc.), the boundaries of the building (e.g., transport and location-oriented indicators) and the assessment of baseline conditions (e.g., processes related to urban management, controllability, and monitoring during the operation phase). Shetabi (2015) presents a more extensive list of forty-five (5) indicators, covering some of the core aspects identified in the ISO but also secondary and tertiary environmental aspects. However, it does not address cultural heritage values, despite being a framework designed to be applied to heritage buildings. The indicators considered in these methodologies are certainly important for comprehensive assessments of the sustainability performance of heritage buildings and "can be required depending on the nature of the case" (ISO 2011). Indicators related to technical aspects, such as safety and state of conservation (Boarin et al. 2014; Gonçalves, Mateus, and Silvestre 2018; Ornelas et al. 2020); social aspects, such as inhabitant's perceptions and community engagement (Leus and Verhelst 2018; Ornelas et al. 2020); and heritage values, including historical, aesthetic, artistic and political values (Havinga, Colenbrander, and Schellen 2019), would be important additions contributing to aa more comprehensive and detailed framework for sustainable conservation of heritage buildings. However, such an extensive tool would increase complexity and imply highly time-consuming procedures, that could discourage its uptake (Leus and Verhelst 2018). As time and economic constraints are two of the main reasons pointed out by practitioners for the lack of application of adequate sustainable conservation practices (Gonçalves, Mateus, and Silvestre 2019), it was a specific goal of this research to establish a set of indicators that is concise enough to ensure feasibility while broad enough to cover all the fundamental aspects of sustainable development, as defined in the international standards (ISO 2011).

6. Future research

The core set of indicators presented, structures fundamental aspects to consider in an assessment method for sustainable conservation. Future research should address how the core set of indicators can be operationalized in a tool to assess the sustainability value of heritage buildings and support decision-making.

Future research should address, issues such as clarity and simplicity in the formulation of indicators (ISO 2011), the relation of the selected indicators with the building attributes (Ornelas et al. 2020), and applicability under time and budget constraints (Gonçalves, Mateus, and Silvestre 2019). Applying such tool in case studies from different categories of Built Heritage (such as industrial, vernacular, urban, modern, etc.), should be a subsequent step for further research, to validate the relevance and availability of information, and to determine the priority and weight of the core indicators suggested in this research. Future research should address the extent to which additional indicators can be added to a baseline framework for sustainable conservation, without compromising the applicability of the framework.

As stated by Cole (2012) "the most significant and necessary shift does not reside at the strategic level, but in the mindset among design team and client participants". A common set of indicators has the potential to improve communication between the multiple stakeholders in the conservation process (Shetabi 2015). Additionally as demonstrated by Leus et al. (2018), it can also contribute to reaching consensus in the management of heritage places. Further research should explore the use of the assessment tool by different stakeholders to reach consensus in decision-making processes, and the contribution of a baseline assessment tool to improve the implementation rate of intentions towards sustainable conservation.

7. Conclusions

The awareness of the importance of Heritage for a more sustainable built environment instigated a rising number of studies developing assessment frameworks crossing heritage and sustainability. However, literature shows the lack of a method to assess the value to sustainability of heritage buildings before redesign interventions. This research aimed at developing a concise framework of indicators for the assessment of heritage buildings, covering the main aspects of sustainability — including cultural values.

The results of this current study show that, despite the differences in structure, scope and aims of the building assessments tools already available, they share common principles towards sustainable development. Site, energy, water, building solutions, materials, durability, indoor environment, community, and values emerge as the main priorities. A baseline assessment framework for sustainable conservation of built heritage requires indicators suitable for existing buildings and that are identifiable at the building scale. It cannot depend upon dynamic indicators related to users and processes that evolve with time and management. Even if indicators related to the operation can be used for detailed assessments of existing conditions before renovation interventions, they do not necessarily provide information related to the building attributes and values on a baseline assessment. Limiting the assessment to a concise set of indicators will always exclude potentially important aspects of sustainability and heritage assessment. However, this approach has the potential to make the process of assessment less time-consuming and more affordable, and, therefore, more feasible in practice.

The resulting selection of indicators for the assessment framework for sustainable conservation of built heritage presents a concise set of twenty-three (23) indicators that cover the fundamental aspects defined in the international standards for sustainability. While the outlined set of indicators is not intended for direct application as an assessment framework, it represents a steppingstone towards building a tool to support decision-making for the sustainable conservation of built heritage. It focuses on existing features of single buildings, making it adequate to inform on the condition of the building before the design stage. It includes indicators related to heritage significance, and, fundamentally, it understands sustainability as a value by itself to be recognised and preserved for future generations.

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