Key Performance Indicators for Building Condition Assessment

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Purpose: The aim of this research is to give to construction industry stakeholders some Key Performance Indicators (KPIs) able to help them making the best decisions when acquiring, operating, maintaining and repairing a building. These KPIs are intended to be included inside a Building Condition Assessment procedure developed by the authors.
Approach: This work is mainly based on two types of KPIs: one, here called Technical index, to assess building degradation and maintenance, so to have a measure of how the asset is getting older; and another, here called Documents index, to measure the quality and quantity of available building documents and thus to know if the building fulfils its legal requirements.
Findings: The proposed KPIs give a picture of the asset current condition, a measure of how it is maintained, the list of its pathologies and also an indication of missing documents.
Research limitations: The KPIs developed are meant to help survey an asset with only visual inspections. In case one or more serious problem are detected, a specific analysis may be required, no matter the final value of the KPIs.
Practical implications: The knowledge about built assets given by these KPIs will help stakeholders in making the best decision when operating or deciding to buy an asset.
Originality: KPIs and Building Condition Assessment procedure are the outcome of an original research that had the purpose of developing instruments for a reliable but quick evaluation of assets condition, to be performed before acquiring them or making major decisions about their refurbishment.

Keywords: Building Condition Assessment, Degradation, Asset management, Decision making

1. Introduction

Operating, maintaining and, eventually, refurbishing constructed assets is every year harder because new performance requirements, as instance UK is now legally bound to reduce emissions by 80% on 1990 levels by 2050 [1], have to be fulfilled whilst assuring economic yield. The owners' requirement of having an economically-efficient asset must, nowadays, be satisfied with the same priority of having, for example, a low CO_2 impact building. As a consequence, decisions of asset managers are becoming more complicated and a deep knowledge of the asset condition is needed [2].

Typically, asset managers must make decisions about maintenance and renewal alternatives based on sparse data about the actual state of their own assets [3] and this often causes the waste of much money: one third of all maintenance costs are used inefficiently as the result of unnecessary or improper maintenance activities [4]. Moreover, researches highlight that most of the stakeholders in the construction industry – designers, contractors, suppliers and owners – are wasting a huge amount of money looking for, validating and/or recreating facilities information that should be readily available. For example, a NIST study [5] estimated that operations and maintenance personnel spent, during year 2002, US $4.8 billion verifying that documentation accurately represented existing conditions of capital facilities, and another US $613 million transferring these data into a useful format.

Assets owners are constantly in search of new solutions to these problems and the outsourcing of maintenance activities is one of the strategies used. In terms of maintenance outsourcing, a set of potential and attractive benefits can be reached such as to reduce maintenance costs, to improve environmental performances, to obtain specialist skills not available in house, to improve work quality, etc.. However, outsourcing also involves a set of drawbacks that must be taken into account, among these [6]:

- loss of control and loss of a learning source, because an internal activity is externalised;
- loss of knowledge of the building;
- possible dependencies on the supplier.

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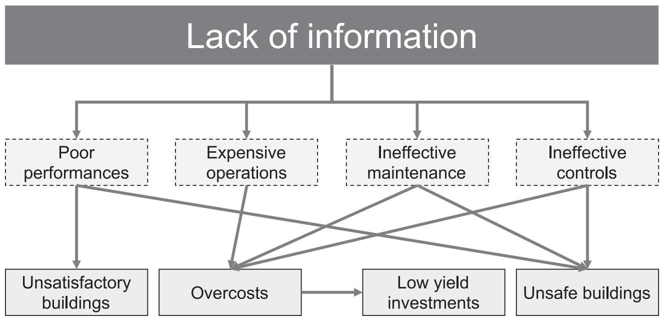

Fig. 1. Main issues due to lack of information on existing buildings.

Maintenance outsourcing is frequently associated to a global service contract: in brief, a company is demanded to manage and perform a set of defined maintenance operations scheduled over a period of time. Frequently happens that the client, to save additional money, does not ask for detailed feedbacks or statistics about components condition; this leads to the loss of important information about the asset. As a consequence of this loss, the client after some time is no more able to control the supplier, its work and asset condition. The Key Performance Indicators (KPIs) herein presented could be used as a valid instrument to monitor building condition over time, even better if the controls are planned periodically through the life cycle of the asset.

Problems related to lack of building knowledge arise also at building handover, when facility managers typically receive many "bankers' boxes" full of information about their facilities. Today those who use information provided must, at best, pay to have the data keyed into the relevant data systems. At worst, facility maintenance contractors are paid to survey the existing building to capture as-built conditions [7].

The lack of information, therefore, causes more or less directly a series of other problems (Fig. 1) that may lead to: (1) the use of unsafe buildings, e.g. buildings that do not comply to basic law requirements; (2) unsatisfactory buildings, e.g. buildings with poor performances; and (3) low yield investments.

To increase stakeholders' satisfaction, this lack of information must be filled and one possible way to improve the knowledge about assets is given by Building Condition Assessment (BCA), e.g. a technical inspection by a competent assessor to evaluate the physical state of building elements and services and to assess facility maintenance needs [8,9]. An asset evaluation achieved through a BCA can be included in the "performance evaluation and improvements" element, which is the basis of the asset management system outlined in the Annex B of the ISO 55000:2014 [10].

The surveys on buildings are the core of a BCA, their depth and outputs become critical when the analysis has to be performed on a building portfolio, because BCA has to help answering complex questions like: how to allocate maintenance budget on different buildings? How to choose the refurbishment alternative that best fits client's needs? Which is the best thermal insulation thickness to be used in a retrofit project? These questions are related to different asset scale, from single components to the entire portfolio, and can be answered using a rating system, consisting of BCA procedures and a set of KPIs, like the one herein proposed. This rating system enables stakeholders to make better choices about their assets; as instance, it is possible to find most damaged components in a building in order to give them a priority when scheduling maintenance operations. But also each building in a portfolio can be analysed, describing it with the proposed KPIs, so to compare it with others to allocate maintenance budget. Moreover, forecasts on the future value of the KPIs if no maintenance is undertaken can be done.

Technical due diligence (TDD) is part of the Facility Management process [12]; TDD consists in the observation of the general physical condition of an asset, looking for deficiencies, with an explanatory report as output. A survey [12] reported that buyers and sellers asked for TDD during handover, but also banks and FM providers use this methodology; the objective is to avoid unexpected costs both during handover and in the starting phase of a FM contract. Facility and asset managers, demanded to make complex decisions about their assets, need to periodically gather reliable and detailed information related to three main fields: physical, functional and financial [11]. Although BCA is mainly aimed at calculating of indicators related to facility's physical condition, it also provides a support for financial indicators computation. KPIs and BCA procedures developed by the authors can be considered a way to perform a TDD, and therefore integrated in the current practice.

Another example of the importance of physical condition indicators, together with financial ones, are given by Shohet and Nobili [13], which developed a performance-based contracting methodology for maintenance; the Building Performance Indicator (BPI) that they defined, related to physical state and fitness for use, is one of the KPIs used as the basis for contracting.

Facility managers are also demanded to make decisions about refurbishment needs of their assets; BCA can be considered a measure of the service quality and therefore fundamental for prioritising renewal [14].

2. Building Condition Assessment

BCA may be seen as a way to improve asset management knowledge and asset monitoring, as well as a method to enhance asset information management. BCA is thus part of the activities aimed to minimise financial and capital costs over the building life cycle while maximising asset value for every stakeholder. The importance of assets knowledge (and therefore of BCA) in a proper asset management programme is highlighted by Foltz and McKay [15] and by Ezovski [16], the latter focusing on commercial buildings. Reliable and objective knowledge of the physical state of their buildings will enable owners to develop appropriate strategies and actions for maintenance, repair, major replacements, refurbishments and investments [9]. All constructed assets should be assessed on an ongoing basis, so the assessment does not necessarily have to be performed all at once; the most effective asset management and reporting is often achieved through a planned condition assessment programme [17].

BCA techniques have been studied since the birth of the necessity of measuring assets performances during their service life [18–22], to consequently maintain them in the most effective way. Baird et al. [23] defined nine different types of evaluation techniques, from empirical to theoretical and from internal to external (Table 1).

Most of the assessment techniques found in literature fits in the categories shown in Table 1. For example, Shohet [24] described some methods, with different objectives and measuring parameters, based on qualitative evaluation criteria (e.g. the surveyor indicates the good/bad state of building components); Johnston et al. [25] defined other techniques, based on cost-driven KPIs and physical state rating, in combination with standards and regulatory compliance checking.

Assessment methods can vary also according to the building scale under analysis: from general (the whole building, if need be, split in macro groups) to particular (only one kind of component: e.g. windows). In the latter case, each component has a specific and detailed evaluation method, like for façades [26], for roofs [27], for rendering façades predictive maintenance [28], for ETICS [29] and for the entire envelope [30].

BCA, as part of the asset management system defined in the ISO 55000:2014 [10], should be conducted in combination with other important activities, like inspections and maintenance operations. Inspections often cause costs overrun if not efficiently organised and must be planned considering what is to be inspected [31]. Maintenance operations, in terms of both scheduling and costing, must be planned consequently to the building assessment to be the most effective as

Table 1
BCA techniques scheme, Baird et al. [23].

	INTERNAL = Immediate answer Context specific Inside the organisation	**HYBRID** = Some of both	**EXTERNAL** = Generalized knowledge Widely applicable Outside the organisation
EMPIRICAL = Experiential knowledge Trial and error	'Work for us' 'Quick and dirty' 'Here and now' 'Try it and see'	'Our experience, and some others experience'	'Works for most/ all' 'Different groups, same experience' 'Generally understood'
DIALOGICAL = Moving between empirical and theoretical	'What works and is true for the group, supported by our experience and internal research'	'What we and others have found from experience, compared with theories derived by us and some others'	'Widespread experience of different groups, compared with widely held theory'
THEORETICAL = Systematized knowledge, Logically deduced	'True for us' 'Our data, our analysis' What the theory says for situation like ours'	'Our theoretical knowledge, and some others theoretical knowledge'	'Scientifically rigorous' 'True for many/most/all' 'Now, and in the future' 'Externally reliable and valid'

possible [32]. BCA is also related to facility management, on which Shohet and Lavy [33] showed possible improvements. In these last years, energy/sustainability-oriented refurbishments, frequently called energy retrofits, became more and more frequent and BCA could provide information to support them [34]; this can be done by linking to the assessment an analysis of building main criticalities and potentials [35,36].

BCA can be joined with a quantitative and objective functionality analysis in order to fully describe a building's fitness for changing missions over its entire life cycle [37].

TOBUS and EPIQR project demonstrated that evaluation techniques, to be more effective, should be targeted to the building function, as instance offices or residential [38–40].

Last but not least, evaluation techniques should give as output an index, a rate or a mark [41,42] to enable decision makers to create a building ranking inside a portfolio in order to prioritise maintenance works and to evaluate refurbishment scenarios.

Even when a condition assessment procedure is defined, the practice of condition assessment by building inspectors yield variable results due to subjective perceptions of inspectors [43]. For example, the subjectivity of building inspectors' prognosis has caused a mean difference of 30% in the maintenance cost estimation in National house condition surveys in Countries such as England and Holland [44]. An improvement in assessment method and reliability by the reduction of the subjectivity element in inspection and by the automation of the inspection process is expected to bring about a 20% increase in productivity in the maintenance industry, which is estimated to be worth 100 billion ECU (European Currency Unit) annually in the EC (European Community) Countries [44].

Starting from both the scheme in Table 1 and the literary review, two techniques to be used have been selected and outlined in Fig. 2. This contains all the main BCA features found in the papers previously quoted and considered relevant for this work.

The analysis of building evaluation techniques showed the extreme difficulty in achieving a detailed survey with a small effort. In order to minimise BCA costs a two-steps approach, as suggested by ASCE/SEI 30-14 [27], has been adopted:

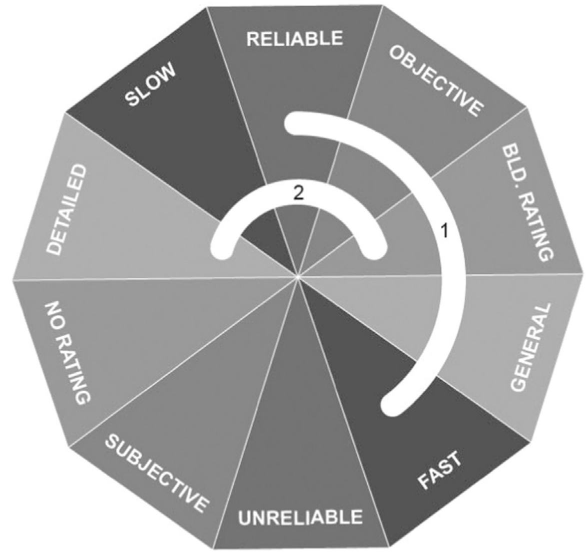

Fig. 2. Two possible building assessment techniques.

1. a preliminary survey on the whole building to rate and to compare it with other buildings in the same portfolio;
2. a detailed survey, focused on portfolio more critical buildings, focusing on more deteriorated components according to the BCA rate.

The survey, either preliminary or detailed, must be:

- reliable: survey results must be precise, detailed as requested, organised in an efficient way (e.g. with different presentation layers), comparable with previous data and also commonly recognised as valid among professionals;
- objective: not heavily influenced by the surveyor's personal judgment and experience;
- associated with one or more KPIs: at the end of the survey the system must provide a KPI able to help in prioritising interventions and easing decisions to be made.

3. KPIs for Building Condition Assessment

Kincaid [45] mentioned that performance measurement is essential in order to perform comparisons and develop strategies for improvement and Lavy et al. [46] emphasised that performance measurement is the key to calibrating the effectiveness of a built facility in a comprehensive manner. Lam *et al.* [47], while working on measuring the success of maintenance projects, stated that when it is not possible to obtain a precise measurement it is usual to refer to performance indicators. Conducting a BCA and computing, from BCA results, some KPIs is therefore the best way to measure the performances of buildings and, besides, satisfying the need of having easily accessible and useful information about buildings and their parts.

Lavy *et al.* made a detailed literature review on KPIs for facilities performance measurement [46,48–50]; they divided KPIs in financial, physical and functional, linking them with qualitative and qualitative metrics and assessment procedures. Lavy et al. [51] also performed some simulations to investigate the importance of KPIs, mainly in relation with the Facility Condition Index (FCI – it is the ratio between maintenance expenditure and current replacement value of the facility) and the Function index (related to the efficiency of space usage). As many other KPIs investigated, the FCI alone is an imperfect measure of the true condition of an asset. The FCI of a building might be higher than the FCI for a utility system; however, the utility system may be more at risk of failure because of the condition of a lower cost component that is critical to its operation. The FCI cannot account for the condition of its critical components and, therefore, on its own, fails to capture this important distinction.

More in general, financial indicators are not the only KPIs to be used to manage a facility: Roberts [52], for school assets, highlighted the necessity of looking at other KPIs than the financial, for example he emphasised the importance of analysing the learning performance indicator in combination with the physical condition ones; this means that the FM process should look not only to the economic part to provide a whole picture of the facility.

Assessing the condition of a facility is a critical aspect of the FM and it involves periodical reporting in relation to the following topics: existing conditions, residual service life of components, funding documents concerning long- and short-term maintenance, and renewal forecasts and recommendations [53]. Among these topics this research highlighted the necessity of mainly two types of KPIs: one (here called Technical index) to assess the building condition in terms of aging and pathologies of its components, taking into account the criticality of the pathologies. The other (here called Documents index) to describe the quality and quantity of available building documents taking into account regulatory requirements. Building owners claim these KPIs, mainly to understand their assets conditions, so to properly allocate budget for maintenance or refurbishment, if need be. Although they may also be used by asset managers, frequently demanded to (but not only): (1) justify their choices about maintenance performed over the year; (2) justify the budget allocated for maintenance and repair operations among multiple assets; (3) control suppliers' work; and (4) track the condition of assets and portfolios over the time.

The data required to calculate the two KPIs described here are gathered through a building survey and through documents checking, without the need of an intensive effort-consuming survey (please refer to the §3.4 for a detailed description of the procedures).

3.1. Technical index

The Technical index of the whole building is a function of the Technical indexes of each building component, thus a standard itemisation (Work Breakdown Structure – WBS) of a building has been created. This WBS, following UNI 8290-1:1981 [54], has been organised through five levels, from detailed to general. The building is broken into: (1) elements materials; (2) technological elements (Elements according to ISO 12006-2:2014 [55]); (3) class of technological elements; (4) technological units; and (5) class of technological units (Construction Entity Parts according to ISO 12006-2:2014 [55]).

The Technical index is calculated for both technological elements (i.e. building components) and technological units; the other three levels are just useful for organisation and comprehension of the WBS itself. The relative importance of each technological unit has been taken into account by two different series of weights: the first related to the construction cost of each technological unit and the second related to its the criticality.

The cost-related weight is proportional to the percentage contribution of each technological unit to the whole building construction cost. The costs have been gathered from literature (e.g. [56]) and the weights computed for many different building functions because the percentage contribution of a technological unit to the whole building cost changes when the function of the building is different.

The criticality-related weight has been assessed with a survey among experts from CNPI (Collegio Nazionale dei Periti Industriali e dei Periti Industriali Laureati – please refer to acknowledgements) who have been asked to fill a pair comparison form, then weights have been computed with the Analytical Hierarchy Process (AHP) [57]. In the pairwise comparison, following Saaty's procedure [57], the relative importance values are determined on a scale from 1 to 9, whereby a score of 1 indicates equal importance between the two elements and 9 represents the extreme importance of one element compared with the other one. A reciprocal value is assigned to the inverse comparison; that is $a_{ij}=1/a_{ij}$, where a_{ij} denotes the importance of the ith criterion compared with the jth criterion. Then, the eigenvector method is used to obtain the local priority vectors for the pairwise comparison matrix (i.e. the weight for each criterion). The consistency of a pairwise comparison can be tested using the consistency ratio (CR), i.e. the ratio of the consistency index (CI) and random index (RI). If the CR is less than 0.1, the pairwise comparison is considered acceptable [57].

Beside WBS and weights, two other instruments are needed for the computation of the Technical index: a Reference Service Life (RSL) database and a list of all possible pathologies for each building component. The database has been built according to ISO 15686-8:2008 [58], starting from a literary review of major existing databases (e.g. [59–61]) and from experts' interviews. Testing or evaluating the reliability of the data contained in the RSL sources is not included in the objective of this research.

Building components pathologies have been classified according to their criticality, using the magnitude of their damages (low, medium and high magnitude) as a parameter, and to their typology, causing either step change (on/off) or gradual change on components. An evaluation of gradual change pathologies extension (low, medium-low, medium-high, high) is required during the assessment. For the ease of use each pathology has been given a univocal code, a name, a description and a measuring parameter. The complete list is made of 431 pathologies.

Pre-formatted diagnostic forms seemed to be the only way to avoid subjectivity due to different cultural background of assessors and to standardise the inspection process, so to have a theoretical BCA as defined by Baird et al. [23]. The diagnostic forms (an extract is given in Fig. 3) created for this research are made of four parts: (1) form data (code, name, number); (2) component data (code, name, notes, age, here called Actual Service Life – ASL); (3) pathologies check list; and (4) indexes output. Totally 438 forms, one per each possible fabric/service component, have been created. The forms are collected in folders, one for each of the 18 technological unit of the WBS.

The Technical index is used to assess building condition by measuring building components service life and degradation. This index is made by three sub-indexes: the first two (here called service life indexes) comparing the ASL of each component with its reference one (RSL) and the third one (called degradation index) evaluating pathologies found on each building component during the inspections. The service life indexes are alternative: if the component has $ASL \leq RSL$, D_C^+ is computed according to Eq. (1); if it has ASL gt; RSL, D_C^- is computed according to Eq. (2).

$$D_C^+ = \frac{RSL - ASL}{RSL} [-] \tag{1}$$

$$D_C^- = 1 - \frac{ASL - RSL}{ASL} [-] \tag{2}$$

The ASL of each component under analysis is computed as the difference between the year of installation and the year of the assessment, as better described in Section 3.4.

The mean of D_C^+ and D_C^- of every component of a technological unit gives the service life indexes (D_{TU}^+ and D_{TU}^-) for the technological units, Eqs. (3) and (4). A technological unit may have both the service life indexes if it contains some components with D_C^+ and others with D_C^-.

$$D_{TU}^+ = \begin{cases} \frac{\sum_{i=1}^{n} D_{C,i}^+}{i} & if\ n \geq 1 \\ 0 & if\ n = 0 \end{cases} [-] \tag{3}$$

$$D_{TU}^- = \begin{cases} \frac{\sum_{j=1}^{m} D_{C,j}^-}{j} & if\ m \geq 1 \\ 1 & if\ m = 0 \end{cases} [-] \tag{4}$$

where:

FORM DATA		COMPONENT DATA		
			CODE	NAME
FORM NUMBER		COMPONENT		
CODE		TECHNOLOGICAL ELEMENTS CLASS	C.V.01	Opaque envelope
	C.V.01.01.03.01--S	TECHNOLOGICAL ELEMENT	C.V.01.01	Vertical opaque envelope
NAME		TYPOLOGY	C.V.01.01.03	External finishing
	FORM -	MATERIAL	C.V.01.01.03.01	Plaster on masonry
		ASL (Actual Service Life)		

SERVICE LIFE INDEX	ASL≤RSL	D^{+}=	
	ASL>RSL	D^{-}=	
DEGRADATION INDEX		A_C=	1.000

ANOMALIES

TYPOLOGY	NAME	DESCRIPTION	PRESENCE [Y/N]	INTENSITY	EXTENSION
LOW anomalies that compromise plaster visual performances	Colour changing	Variation of one or more parameters that define the color (hue, clarity, saturation), discoloration of the finish, oxidation and tarnishing of surfaces, rust spots and permanent stains on plaster and cement		Visibility of the degradation, contrast level and residual brightness of finishing	
	Surface deposits	Accumulation of urban atmospheric dust or other foreign material, of variable thickness, inconsistent and not adhering to the surface of the coating		Nature, texture and thickness of the deposits	
	...	...		...	

Fig. 3. Extract of a diagnostic form (plaster).

- n is the number of components with $ASL \le RSL$ in a technological unit;
- m is the number of components with $ASL > RSL$ in a technological unit.

The last step of service life indexes computation for the entire building consists of a weighted average, Eqs. (5) and (6), of the technological units indexes using weights described above (an example is given in Table 2):

$$D_{Bld}^{+} = \frac{\sum_{k=1}^{o} D_{TU,k}^{+} * W_k^{E/C}}{\sum_{k=1}^{o} W_k^{E/C}} \quad [-] \tag{5}$$

$$D_{Bld}^{-} = \frac{\sum_{k=1}^{o} D_{TU,k}^{+} * W_k^{E/C}}{\sum_{k=1}^{o} W_k^{E/C}} \quad [-] \tag{6}$$

where:

- o is the number of technological units under exam (the BCA can be limited to some technological units and it can ignore others);
- $W_k^{E/C}$ means that alternatively economic and criticality weights can be chosen.

As written above, the weights (economic or criticality) $W_k^{E/C}$ are assigned to each technological unit under assessment. The values have been decided by the authors, together a panel of CNPI experts using the AHP method [57]. In Table 2 there is the list of weights used for residential buildings; in addition to them, weights for other building functions have been calculated (hospital, hotel, tertiary – office, school and tertiary – production).

The last part of the Technical index is the degradation index, which is computed for each assessed component as a weighted mean of three values: A_L; A_M; A_S.
A_L, Eq. (7), is a measure of how many low criticality pathologies are detected on the component; A_M, Eq. (8), of how many medium criticality pathologies and A_S, Eq. (9), of how many high criticality pathologies. They are computed as follow:

$$A_L = \frac{\sum_{i=1}^{L} P_{L,i} * E_i}{L} \quad [-] \tag{7}$$

$$A_M = \frac{\sum_{j=1}^{M} P_{M,j} * E_j}{M} \quad [-] \tag{8}$$

$$A_S = \frac{\sum_{k=1}^{S} P_{S,k} * E_k}{S} \quad [-] \tag{9}$$

where:

- L is the maximum number of low criticality possible pathologies for the component as in the diagnostic form;
- M is the maximum number of medium criticality possible pathol-

Table 2
Weights associated to technological units (residential buildings).

	TU01	TU02	TU03	TU04	TU05	TU06	TU07	TU08	TU09
Economic W^E	2.75%	2.75%	19.50%	9.85%	5.85%	1.85%	0.75%	5.05%	10.85%
Criticality W^C	5.62%	4.53%	4.08%	7.07%	6.93%	2.61%	4.61%	13.69%	3.76%
	TU10	**TU11**	**TU12**	**TU13**	**TU14**	**TU15**	**TU16**	**TU17**	**TU18**
Economic W^E	8.15%	1.05%	2.30%	12.70%	6.65%	6.55%	1.35%	1.80%	0.25%
Criticality W^C	3.76%	0.62%	0.62%	3.90%	8.95%	9.23%	9.23%	5.67%	5.13%

ogies for the component as in the diagnostic form;

- S is the maximum number of high criticality possible pathologies for the component as in the diagnostic form;
- P is the presence (1) or absence (0) of a pathology as observed by the assessor on site;
- E is the extension (from 0% to 100% – in case of step change anomaly it is 100% if there is the anomaly and 0% if there is not; otherwise it can assume four values: low extension 25%, medium-low 50%, medium-high 75% and high extension 100%).

The number of pathologies detected is the summation of $P_L+P_M+P_S$ for each component. The parameter E is a qualitative measure taken by the assessor during the survey; e.g. the plaster on a wall can be completely detached (E = *high extension* = 100%) or detached only in a small portion (E = *low extension* = 25%).

These three partial indexes are aggregated in one, describing the component condition, through the weighted average of Eq. (10):

$$A_C=\frac{A_L*W_L+A_M*W_M+A_S*W_S}{(W_L+W_M+W_S)=1}=A_L*W_L+A_M*W_M+A_S*W_S\,[-] \qquad (10)$$

where the weights are:

- low: W_L=10%;
- medium: W_M=30%;
- serious: W_S=60%.

These weights have been established by the authors with the help of CNPI experts using AHP method [57] and have been tested in the case studies to assess their reliability. The weights are related to types and criticality of pathologies, this one measure by the magnitude of the damages caused: (1) low magnitude of the damages, pathologies mainly related to the finishing; (2) medium magnitude of the damages, pathologies affect the component and its functionality; and (3) serious magnitude of the damages, the component is not working properly or at all.

The three indexes (A_C, D^+_{Bld} and D^-_{Bld}) are used to address two main themes: components aging and obsolescence [62,63]. When a component reaches its RSL limit (i.e. $ASL = RSL$) it means that it should be replaced but not all the components are replaced when their ASL is equal to their RSL. In the real word, the service life of buildings is often conditioned by economic reasons [64]. When inspecting a building, a component can be found more or less deteriorated and may be more or less aged, the scenarios are: (1) components in good condition, $ASL \le RSL$; (2) components in good condition, $ASL > RSL$; (3) components in bad condition, $ASL \le RSL$; and (4) components in bad condition, $ASL\,\mathrm{gt};RSL$. Cases (1) and (3) are clear: in the former no maintenance is required, while in the latter maintenance is required but no replacement is needed. Case (4) means that the component has not been maintained properly and it also exceeded its RSL, so it must be restored or replaced. Eventually, case (2): although a component is older than its RSL, it has been maintained properly and it is still in use. The three indexes give a detailed picture of building components obsolescence and degradation; this information is crucial for building stakeholders.

The degradation index for technological units is computed, as in the service life indexes, using Eq. (11):

$$A_{TU}=\frac{\sum_{i=1}^{q}A_{C,i}}{q}\,[-] \qquad (11)$$

where q (which is the sum of n and m calculated in the degradation index) is the number of components inside the selected technological unit.

The degradation index for the whole building is the weighted average of technological units degradation index. Weights and equation are the same as for service life indexes, Eq. (12):

$$A_{Bld}=\frac{\sum_{k=1}^{o}A_{TU,k}*W_k^{E/C}}{\sum_{k=1}^{o}W_k^{E/C}}\quad[-] \qquad (12)$$

where:

- o is the number of technological units under exam;
- $W_k^{E/C}$ means that alternatively economic and criticality weights can be chosen.

Eventually, when the three indexes (D^+_{Bld}, D^-_{Bld} and A_{Bld}) are known, a Technical index for the whole building is computed as the comparison between the condition of the assessed building and an optimal one of the same age but without any anomaly (A_{Bld}=100%) and maintained properly (D^-_{Bld}=100%). In Fig. 4, the ideal building is represented by the dashed line triangle and the assessed one by the continuous line triangle; the building Technical index is the ratio between the area of the two triangles, Eq. (13).

$$I_{Tech}=\frac{Area_{Building}}{Area_{Optimal}}\,[\%] \qquad (13)$$

The two triangles in Fig. 4 show:

- dashed line: the best situation in which the building can be. No anomalies (A_{Bld}=100%), all the components have been replaced according to their RSL (D^-_{Bld}=100%). D^+_{Bld} represents the age of the building, which physiologically gets older. This triangle represents the best results that the building can achieve during the assessment;
- continuous line: the actual building condition. Index A_{Bld} decreases when anomalies are found and D^-_{Bld} decreases when one or more components pass RSL limit. D^+_{Bld} is always equal to the dashed one because, as written above, ageing is physiological.

The more the area of the continuous line triangle is smaller than the area of the dashed line one, the more the building has a low Technical index, Eq. (13). A small area means the presence of a lot of anomalies and of components that are older than they are supposed to be because no maintenance has been done on the building. Therefore, a low Technical index can be seen as an indicator of a building that does not fully satisfy its required performances (in terms of pathologies, components to be replaced and/or obsolescent). The Technical index is not suitable for heritage buildings, which frequently require specific procedures and assessment tools.

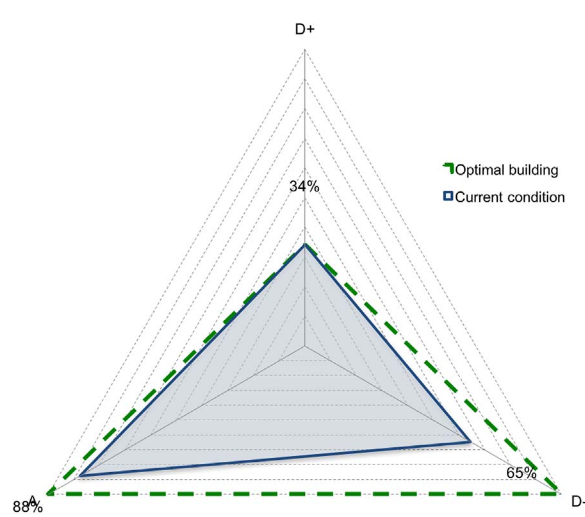

Fig. 4. Example of graphical output for Technical index.

3.2. Documents index

The second KPI is the Documents index, a weighted ratio between the number of available documents and the number of documents that should be available for the specific building; the weights take into account the different importance of documents families (e.g. fire safety, land register, structure, etc.). As for the Technical index, weights have been computed with AHP techniques after a pair comparison made by experts from CNPI. The starting point for this evaluation of relevant technical documentation is a list of required documents.

Each technical document, required either by Italian law or by standard practice, has been listed and all the documents have been grouped for classification purpose in nine documents families. Some categories may be not mandatory for a specific building (e.g. in Italy not every building needs fire safety documentation), so, depending on the actual number of active families, their weights are redistributed.

Documents inside each family are organised in four categories according to their importance: (1) Level 1: mandatory documents, their absence implies illegal or unsafe building use; (2) Level 2: required documents, their absence does not imply illegal building use; (3) Level 3: important documents, not required by law; and (4) Level 4: documents with just explanatory purpose (non-exhaustive list). The difference between Level 1 and Level 2 is that the former includes documents and certificates that the building owner must have to legally and safely operate the asset, while the latter includes documents (usually) required to gather authorisations and certificates (e.g. drawings, design documents, documents related to in-use tests to get certificates). Level 3 documents are important for building knowledge (e.g. as-built drawings, maintenance plan) but not required by law or necessary to obtain permissions. Level 4 is just a collection of documents produced during the building life cycle, not required by law and not directly useful for building operation. A weight is associated to each level of importance (Table 3); these weights have been defined by authors and CNPI experts with the AHP technique.

The calculation of the Documents index starts with the evaluation of each document score, obtained multiplying importance weight and presence, Eq. (14).

$$P_{doc}=presence*importance\,[-] \tag{14}$$

where presence is 1 if the document is available and 0 if not and importance is the weight related to the level, as listed in Table 3.

Once the scores of all technical documents have been computed, the score of a family, P_{eff}, is obtained as the sum of the scores of all the documents pertaining to the family, Eq. (15):

$$P_{eff}=\sum_{i=1}^{n}P_{doc,i}\;[-] \tag{15}$$

The score of the family, the value provided by the Eq. (15), is then divided, Eq. (17), by the sum of the scores of all the necessary documents (Level 1, 2 and 3) of the family, whether they are present or not, Eq. (16):

$$P_{max}=\sum_{i=1}^{n}P_{doc,i}^{necessary}\;[-] \tag{16}$$

$$P_{family}=\frac{P_{eff}}{P_{max}}*100\quad[\%] \tag{17}$$

Table 3
Importance weights of documents levels.

Level	Importance
1	0.55
2	0.42
3	0.03
4	0.00

Table 4
Documents family weights calculated with AHP for residential building.

#	Technological unit	Weight [%]
01	A – Construction	8.41%
02	B – Fire safety	19.86%
03	C – Structures	26.09%
04	D – Services	17.60%
05	E – Safety and maintenance	7.16%
06	F – Urban planning	3.64%
07	G – Land register	2.30%
08	H – As Built	12.80%
09	I – Origin and rights	2.14%

Eqs. (15) and (16) are just intermediate steps to calculate the Documents Index for each family, which is, in essence, the ratio available to required documents – Eq. (17) – multiplied by the weight of the family Eq. (18):

$$I_{family}=P_{family}*Weight_{family}\quad[\%] \tag{18}$$

The families weights $Weight_{family}$ are not linked to the economic value of the building, they are related to the importance of the family in the context of a specific type of building (residential building, office building, hospital, ...). An example of weights for a residential building is shown in Table 4, the AHP technique has been used to calculate the values starting from pairwise comparison made by CNPI experts.

The sum of all the computed weighted family indexes is the document index, Eq. (19):

$$I_{Doc}=\sum_{i=1}^{N}I_{family,i}\quad[\%] \tag{19}$$

The result is a number between 0 and 1, where 1 is the best case, all needed (Level 1, 2 and 3) documents are available and 0 the worst case, where no document is available.

Results are summarised in a Kiviat graph (Fig. 5) with two different series of data:

- the dashed line represents the condition of a building having all the documents required by law and only those (i.e. all the Level 1 documents and none of Level 2, 3 and 4). It is a minimum level of documentation and it should be noticed that the number of Level 1 documents in a family depends on many factors, among the others the building function and the type of owner (Public or Private);
- the continuous line is the actual building condition and it joins the values of the nine family indexes. The continuous line (building under analysis) should be greater than the dashed one. Even if this happens it is still possible that some Level 1 documents are missing

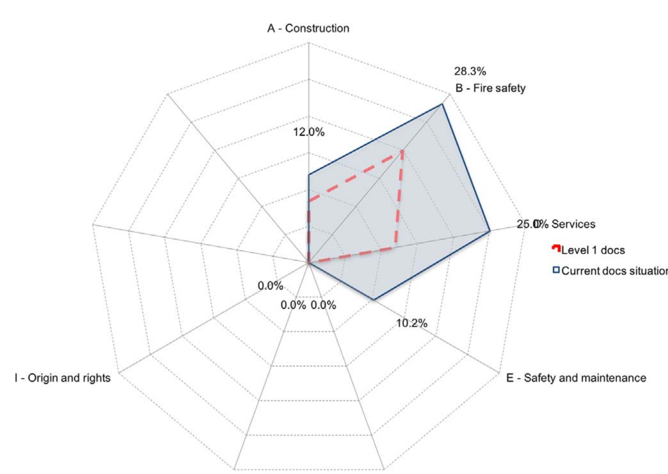

Fig. 5. Example of graphical output for Documents index.

and thus some alerts have been appositely created to overcome this issue (please refer to the Table 5).

3.3. Building index

Regardless of user's background and experience, a single KPI is better understood than two (Technical and Documents indexes) or, even worst, four (D^+, D^-, A, I_{Doc}); but combining the two proposed KPIs into a single one for the whole building is challenging. The main problem is losing information during the aggregation: the information given by a single index could be misunderstood without an appropriate explanation (such as a report).

The Building Index I_{Bld}, is computed as the simple average of Technical and Documents indexes, Eq. (20). In case one of the two indexes is not calculated (the client may be interested in just one of the aspects), either Eq. (21) or Eq. (22) is used.

$$\boldsymbol{I_{Bld}}=\frac{\boldsymbol{I_{Tech}}+\boldsymbol{I_{Doc}}}{\mathbf{2}}\quad [\%] \tag{20}$$

$$\boldsymbol{I_{Bld}}=\boldsymbol{I_{Tech}}\,[\%]\ \textit{if only technical assesment required by client} \tag{21}$$

$$\boldsymbol{I_{Bld}}=\boldsymbol{I_{Doc}}\,[\%]\ \textit{if only document assesment required by client} \tag{22}$$

To avoid misunderstanding the index is always presented together with the Technical index graph (Fig. 4) and the Document Index graph (Fig. 5) in a dashboard (an example in the case study, Fig. 7) accompanying a short report. A weight average instead of a simple one can be used to combine the two KPIs according to clients' needs and interest. In authors' experience some clients had even avoided the computation of one of the two indexes.

3.4. Assessment procedure

The way to use procedures and tools developed is briefly presented in this paragraph with the aim to clarify use and potential of the KPIs. The Technical index is computed by filling diagnostic forms (Fig. 3); the number of forms to be filled is connected with the type of analysis (Fig. 2) and to the needs of the client: building assessment can be either preliminary, looking at the main components, or detailed, looking at each single component. The number of diagnostic forms does not influence the results (please read further reasoning in the §5), so the assessment process can be done incrementally, increasing the detail over the time.

The assessment, like most BCA, is based only on visual inspections made by a competent assessor leaving specific on site analysis, measurements or tests to experts that should be called on the basis of the BCA. During the survey, the assessor fills the diagnostics forms with the *ASL* [53], i.e. the age (measured in years) of the component under analysis calculated as the difference between the year of the assessment and the year of installation/construction, and with a guided qualitative evaluation of component's pathologies. The assessor should check if one or more pathologies listed are visible on the component and give a qualitative measure of their extension. In addition to the previous data, some notes, names, codes and general data about the asset and its part have to be recorded by the assessor.

The proposed standardised procedure for building survey requires, depending on the building size, few hours of work. The time spent on site depends also from the type and objective of the survey, which can be either preliminary (just checking public zones and services) or detailed (checking all building components and services individually). In particular, filling a diagnostic form takes just one minute, as each form includes an average of 25 fields to be filled.

The calculation of the Documents index involves the checking of the presence/absence of a series of documents and is influenced by the organisation of client's archive: in a well organised data room it requires less than an hour. If documents are scattered in multiple offices and not readily available, days may be required.

4. Case study

A typical Italian residential building has been chosen as a case study (Fig. 6); it is a multi-storey building divided into independent flats, built in 1950, located in the town centre of Milan, in Italy. It consists of 5 storeys above ground (the last has been made two years after the others, in a second step) and a basement. It has a main façade looking outward to the street and a rear one faced on the inner courtyard. The minor sides are in direct contact with two existing buildings of the same age. Ground floor is dedicated to offices whilst floors from the first to the fifth are residential; the basement hosts the heating system and private cellars of the users. The main façade is made of cement exposed bricks except for the ground storey, which is stone cladded; the inner façade is covered with plaster and painted. Original windows have a wood frame and single glazing; some of them have been replaced with PVC windows with double-glazing. Structures are in reinforced concrete and façades have been realised with cavity walls made of clay bricks without insulations. The pitched roof is covered with clay tiles. During these years only standard maintenance has been done on building components, whilst services have been refurbished to meet new to binding laws and standards.

In this case study a preliminary survey on building public zones has been performed. Totally 32 components (contained in 9 technological units) have been analysed. The procedure consists of two main steps: documents analysis, to compute the Document index, and building survey, to obtain the Technical index. Evaluating documents as first step helps the surveyor in understanding the building (its technologies, services and layout), so it is possible to assess the degradation with less effort and more precision. Economic weights of Table 2 have been used in the calculation of Documents and Technical indexes.

Table 5 shows that the building documents situation is abundantly above the minimum: all the mandatory documents (Level 1) are present and there are also many of those of Level 2 and 3. As-built documents, not mandatory in Italy but nevertheless considered very important (their weight is 18.22%), are missing and their lack lowers the final evaluation to approximately 79%.

Check/uncheck symbols (✓/✗) in Table 5 help users in understanding if all mandatory documents (Level 1) are present (✓) or absent (✗); the complete documents checklist shows what are the missing documents each single family. To be noticed that documents for structures and urban planning are not mandatory for the building under analysis, so they have not been considered in the assessment. Results of the building survey are shown in Table 6, technological units not surveyed are grey.

Fig. 6. Case study main façade.

Table 5
Documents index of the case study

Doc. family		Weights [%]	Score [-]	Max score [-]	Family score [%]	Weighted score [%]
A - Construction	✓	11.97%	0.55	0.55	100.00%	11.97%
B - Fire safety	✓	28.26%	1.10	1.10	100.00%	28.26%
C- Structures						
D - Plants	✓	25.05%	6.50	6.50	100.00%	25.05%
E - Safety and maintenance	✓	10.19%	0.03	0.03	100.00%	10.19%
F- Urban planning						
G - Land register	✓	3.27%	0.42	0.42	100.00%	3.27%
H - As Built	✓	18.22%	0.00	0.03	0.00%	0.00%
I - Origin and rights	✓	3.05%	0.00	0.09	0.00%	0.00%
				Documents index		**78.74%**

The analysis highlighted that many components exceed their RSL (they were not replaced when they should have been) and most of them do not fulfil their requirements. More than 25% (133 on 407) of the anomalies listed in the diagnostic forms have been found but this is not a big issue because degradation affects mainly finishing and non-critical components; that is why the final mark of the index *A* is 88%. The last column of Technical Index summary (Table 6) shows the number of observed anomalies related to the maximum one as a total and split for each technological unit.

At the end of the analysis a short report can be drawn, with synthetic data and short remarks about documents, degradation and remaining service life, as outlined in Fig. 7.

This summary report seems to be really useful for building owners, tenants and managers, who only need to know the current building condition leaving the detailed data in the full report to technicians and engineers that need them to plan maintenance and renovation works. Moreover, the combination of summary data and graphs helps in understanding immediately criticalities and refurbishment potentials.

5. Discussion

Several case studies (15 buildings of different ages and functions, Table 7 and Fig. 8) have been analysed and some correlations among variables searched. Further investigation is needed but it seems that the building condition (Technical index) is loosely coupled to the year of construction (Table 8). Case studies proved that, regardless of the construction year, the more the maintenance is planned and organised properly, the higher is the Technical Index, suggesting that this KPI may be used as a good measure of the effectiveness of the maintenance policy adopted for a building.

Furthermore, Table 8 shows that there is no correlation between the Technical index and the number of diagnostics forms used during the survey (i.e. the number of components inspected), this allows for a two-step condition assessment: the first one (preliminary) inspecting only the most important components and the second one (detailed) examining every part of the building.

The procedures and tools have been tested by different categories of users (e.g. specialists, surveyors, students) providing KPIs without any significant difference. KPIs can be used to assess a portfolio or a single asset, to achieve a reliable picture of buildings degradation, ageing and documents situation, so to provide the basis for budget allocation, maintenance or refurbishment works.

6. Conclusions

“Performance evaluation and improvements” is a key element of an asset management system according to ISO 55000:2014 [1] and the proposed KPIs, based on a standardised inspection procedure, may be used as a building performance metric; moreover, the KPIs developed can be used to perform a technical due diligence to be used in case of handover, in the FM contract definition [12] and in case of refurbishment strategies prioritisation [14]. The periodic assessment of the condition of an asset, together with a detailed reporting, is a critical activity in the facility management field; the joined information given

Table 6
Technical index of the case study

Technological units			Weights [%]	Weighted indexes			Anomalies #
#	Name	Forms #		D^+	D^-	A	
01	Foundations						0 of 0
02	Retains structures						0 of 0
03	Elevation structures						0 of 0
04	Opaque envelope	5	20.41%	2.72%	13.27%	19.14%	22 of 90
05	Transparent envelope	8	12.12%	1.26%	6.06%	9.34%	44 of 105
06	Slab of ground	1	3.83%	0.00%	1.92%	3.52%	3 of 13
07	Slab on open spaces						0 of 0
08	Roof						0 of 0
09	Internal vertical partition	5	22.49%	0.00%	13.87%	17.97%	26 of 52
10	Internal horizontal partition	4	16.89%	0.00%	11.96%	16.47%	9 of 66
11	External vertical partition	1	2.18%	0.00%	1.99%	1.77%	7 of 20
12	External horizontal partition	2	4.77%	0.00%	2.18%	2.55%	17 of 27
13	HVAC						0 of 0
14	Water and sanitary plant						0 of 0
15	Electric plant	4	13.58%	10.41%	13.58%	13.49%	3 of 22
16	Sewer plant						0 of 0
17	Lift plant	2	3.73%	0.00%	2.49%	3.45%	2 of 12
18	Fire plant						0 of 0
Total		**32**	**100.00%**	**14.39%**	**67.32%**	**87.70%**	**133 of 407**
					Technical index		**63.17%**

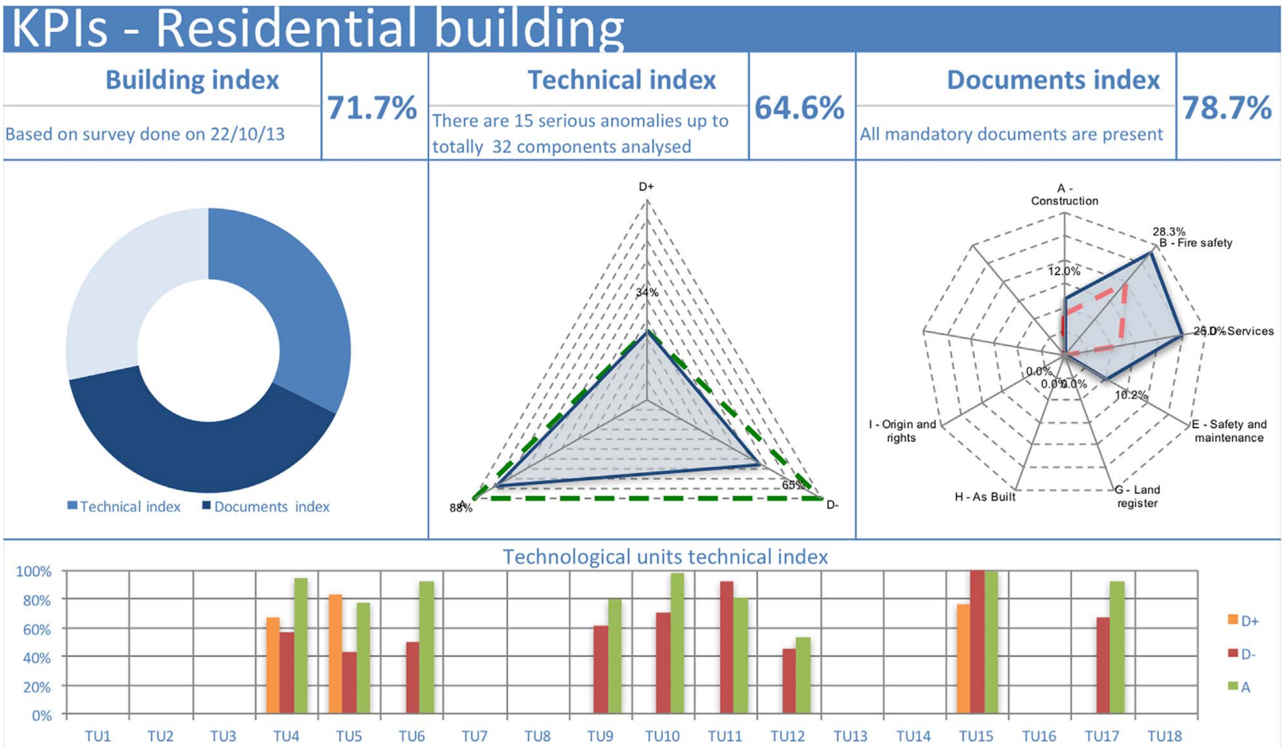

Fig. 7. Final synthetic report of the case study.

Table 7
Results obtained from 15 case studies of different ages and types.

Code	Type of building	Construction year	# High Criticality anomalies	# Technical Unit	# Forms	Technical index
1	Residential multi-family multi-storey building	1933	41	9	50	62%
2	Residential multi-family multi-storey building	1953	15	9	32	65%
3	University building (classrooms and offices)	1966	36	12	57	67%
4	Office building (previously residential)	1890	4	16	135	69%
5	School (nursery, primary, secondary, college)	1895	0	18	47	99%
6	Residential multi-family multi-storey building	1969	5	7	13	73%
7	Residential multi-family multi-storey building	1954	56	11	128	57%
8	University building (library, classrooms and offices)	1920	13	8	29	63%
9	Primary school	1946	26	12	33	54%
10	Oratory	1953	101	7	75	40%
11	Shopping centre	1994	4	11	49	89%
12	Shopping centre	2002	4	11	41	98%
13	Shopping centre	1998	6	10	35	96%
14	Shopping centre	2000	13	11	40	94%
15	Shopping centre (with offices and apartments)	1998	20	11	50	89%

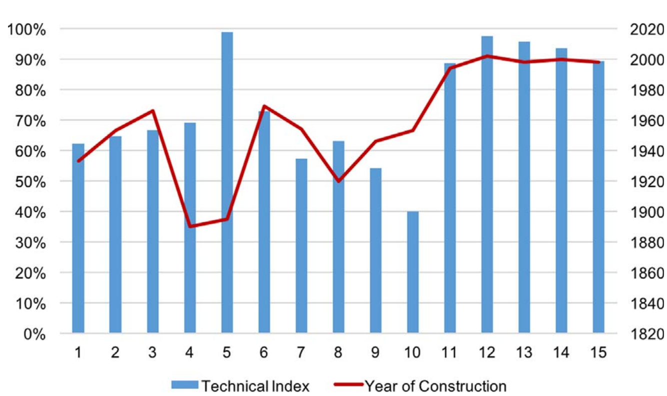

Fig. 8. Technical index and construction year of the case studies.

by (Building, Technical, Documents) indexes and diagnostic forms allow decision-makers to base their choices about assets on reliable data, avoiding most of the consequences of the lack of information in property and facility management.

The KPIs developed are meant to be used by owners, asset and portfolio managers to deepen the knowledge of their asset, so to make the right decisions, allocate budget wisely and control suppliers' work over the time. The reliable and objective knowledge of the physical state of their buildings obtained with the proposed BCA procedure will enable owners to develop appropriate strategies and actions for their asset management.

The advantages given by the use of this BCA procedure and connected indicators are connected to the improvement of these activities: the possibility of objectively assessing the portfolio, comparing different assets, producing the list of components to be restored or replaced, checking an asset during the handover, producing the list of

Table 8
Pearson correlation coefficients among some variables of the BCA.

	Construction Year	# High Criticality Pathology	# Forms	Technical index
Year of Construction	1	0.4991	−0.4205	0.5658
# High Criticality Pathology	0.4991	1	0.3676	−0.7954
# Forms	−0.4205	0.3676	1	0.1911
Technical index	0.5658	−0.7954	0.1911	1

present/absent documents, with the related expiry dates and eventually controlling the maintenance suppliers' observance of the contract.

The technical KPIs are limited to the visual checking of components condition, no inspection with instruments is undertaken. Specific on site analysis, measurements or tests are to be done by experts to examine in depth problems highlighted by BCA. This limitation, quite common in BCA procedures found in literature, is actually an advantage, as it allows for a fast and cheap assessment of the building.

The Documents index provides a detailed output that can be understood even by stakeholders without a technical background. Even if it is based on a check of documents and neglects any coherence check between what is in the documents and the actual building condition, check to be done on site during the assessment, it proved to be a useful tool when performing due diligences. Moreover, the documents check list can be used as list of documents to be produced during the design phase of refurbishment/retrofit projects.

The KPIs may also be connected to additional economic indicators, so to allow for the calculation of costs related to restoration, planned maintenance and retrofit. Besides this possible connection, the KPIs have a great potential also used as a stand-alone benchmarking system: they have been created to answer the need of many asset and portfolio managers, looking for instruments and procedures, easy to be used, reliable and adaptable to heterogeneous assets.

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