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EFFICIENCY INDEXES FOR BUILDING CONDITION ASSESSMENT

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ABSTRACT

Building condition assessment has become more and more important in the last years because it is essential at any time of buildings life. An assessment is absolutely necessary, for instance, in building takeovers to know what one is going to buy or it can be used to measure global service contracts success; similarly, to be aware of the building actual condition is important when planning maintenance. Condition assessment process results, in this research, are given by an efficiency index, made of an index assessing anomalies and two assessing degradation, pertaining to the whole building. Although the building assessment is obtained through a global index, which is computed from indexes assessing each building component degradation and anomalies so a deep knowledge of building condition is assured.

In order to compute the degradation index, building components service life is compared to a Reference Service Life database. The two possible cases, either the service life of the component is smaller than the RSL or it is bigger, generate two different indexes here called D+ and D-. In order to compute the anomalies index building components anomalies are compared to a defined set of anomalies, which are categorized by typology, gravity of the damage and extension, and an index, here called A, measuring numbers and extensions of existing anomalies is created. Once building components have been assessed the information about their degradation (D+ and D-) and anomalies (A) of each component are grouped in building components families and then the three indexes of each family are grouped in indexes for the whole building. This index may be used in conjunction with another one assessing the building technical documents quality to reach a final index describing the whole building; both of them are supposed to be integrated in the building logbook.

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In this paper two case studies are presented in order to show how the building efficiency index works, how the intermediate results may be useful and to prove the effectiveness of the methodology.

Key words: building condition assessment, building degradation, building anomalies, service life

Introduction

Owners and users of buildings, regardless of their functions, are often faced with questions like 'Is the maintenance policy adequate?'; 'Is the building getting older properly?'; 'Is the building losing its economic value?'.

The aim of this paper is to show how an easy, fast, cheap and reliable condition assessment tool can answer these questions. This tool may be used in conjunction with a tool to assess quality and quantity of technical documents of the building [9, 10] in order to have a complete picture of the building: the two information together may, for example, measure how suitable the building is for owners or users purposes.

Condition assessment has quite standard procedures [1, 2] but most of the methods [1, 4, 6, 7] either lack on giving information on building components state because are too focused on assessing the quality of building spaces or are too sensitive to human subjectivity. In this research building condition assessment is done by filling well guided diagnostic forms connected with two indexes, one related to the component service life and the other to the pathologies detected. This procedure eventually provides an index describing the whole building and all its analyzed parts.

Technical Efficiency Indexes

The technical efficiency index is the output of a building assessment from two different points of view, one related to its service life and the other to its possible anomalies. The assessment is made from bottom to top, i.e. starting from building components and arriving to the whole building, using a database of building components Reference Service Life (RSL) [8] and anomalies, classified by damage magnitude (minor, medium and serious) and behavior (gradual change or step change). This database is used to feed diagnostic forms during the necessary building surveys. Each building component has its own diagnostic form (more than 400 forms has been created) and these forms are grouped into eighteen building components families (Elevation structures, roof, HVAC, etc.) according to UNI 8290-1 standard.

During the survey each building component is described by two indexes; the first index, which can be called 'Service Life Index', depends on the component actual service life (here called ASL). If ASL is under or above the component RSL the index is respectively called D+ or D-, both going from 1 (good) to 0 (bad). The first one, D+, measures how many years remain to reach the RSL, while the second, D-, measures how much time has passed from the RSL. The second index, which can be called 'Anomalies Index', is a weighted ratio between the encountered anomalies and all the possible ones for the specific component.

The mean of the indexes of all components pertaining to a family gives the three indexes for the family. Each of the eighteen building components families has a relative importance weight, calculated starting from its construction cost, and the three indexes D+, D- and A for the whole building are computed as the weighted mean of the indexes of each family. The use of a weighted mean where the weights are proportional to the construction cost of each family makes degradation and anomalies on components with higher construction cost more important than the ones on low construction cost components, i.e. the building indexes are more affected by degradation and anomalies on expensive components than by that ones on cheap components.

The computed building efficiency indexes describe the condition of the building with three numbers that vary from 100%, the best condition, to 0%, the worst one. They can be combined into a single index using formula [11], which compares the area of the triangle depicting the actual condition of the building with the one for the optimal building (please see the Figure inside Table 1).

Table 1 : Technical efficiency index

$$AD^{+}_{Bld} = \sqrt{A^2 + D^{+2} - 2 * A * D^{+} * \cos\left(\frac{2}{3} * \pi\right)} \quad [1]$$

$$AD^{-}_{Bld} = \sqrt{A^2 + D^{-2} - 2 * A * D^{-} * \cos\left(\frac{2}{3} * \pi\right)} \quad [2]$$

$$D^{+}D^{-}_{Bld} = \sqrt{D^{+2} + D^{-2} - 2 * D^{+} * D^{-} * \cos\left(\frac{2}{3} * \pi\right)} \quad [3]$$

$$P_{Bld} = \frac{AD^{+}_{Bld} + AD^{-}_{Bld} + D^{+}D^{-}_{Bld}}{2} \quad [4]$$

$$AD^{+}_{Opt} = \sqrt{1 + D^{+2} - 2 * D^{+} * \cos\left(\frac{2}{3} * \pi\right)} \quad [6]$$

$$AD^{-}_{Opt} = \sqrt{2 - 2 * \cos\left(\frac{2}{3} * \pi\right)} \quad [7]$$

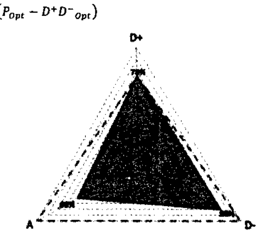
$$D^{+}D^{-}_{Opt} = \sqrt{D^{+2} + 1 - 2 * D^{+} * \cos\left(\frac{2}{3} * \pi\right)} \quad [8]$$

$$P_{Opt} = \frac{AD^{+}_{Opt} + AD^{-}_{Opt} + D^{+}D^{-}_{Opt}}{2} \quad [9]$$

$$Area_{Bld} = \sqrt{P_{Bld} * (P_{Bld} - AD^{+}_{Bld}) * (P_{Bld} - AD^{-}_{Bld}) * (P_{Bld} - D^{+}D^{-}_{Bld})} \quad [5]$$

$$Area_{Opt} = \sqrt{P_{Opt} * (P_{Opt} - AD^{+}_{Opt}) * (P_{Opt} - AD^{-}_{Opt}) * (P_{Opt} - D^{+}D^{-}_{Opt})} \quad [10]$$

$$I_{TechEff} = \frac{Area_{Building}}{Area_{Optimal}} \, [\%] \quad [11]$$



Building (continuous line) – Optimal (dashed line)

The technical efficiency index is a measure of how much the building condition is far from its best possible condition (not from the condition of the new building), i.e. the condition in which the building can be, if maintenance is performed as it is supposed to be and there are no anomalies.

Case Studies

Many case studies have been prepared to prove usability and effectiveness of the technical efficiency index, in this paper an application on two residential buildings is presented; for one of them it will also be shown how the technical index may be summed up to another describing quality and quantity of technical documentation of the building [9, 10].

Residential Building in Milan

The first case study is a residential building in Milan, built in 1953, with 5 storeys above ground level and one under, the main façade facing the road (Figure 1) is cladded with tiles and the other, facing an inner courtyard, has a plaster finishing. The survey, as requested by client, dealt only with public parts, façades and windows of the building.

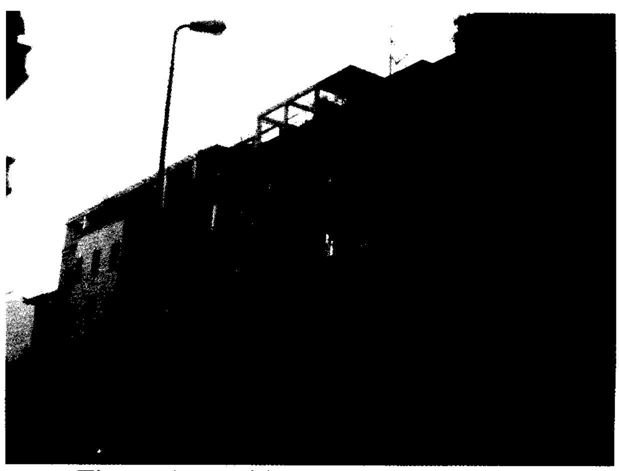


Figure 1 : Residential building in Milan

The first step is the evaluation of all the building components (both construction and plants) in terms of ASL and anomalies: totally 32 forms, similar to the one showed in the Figure 2, have been filled.

FORM DATA		COMPONENT DATA		
			CODE	NAME
FORM NUMBER	01	COMPONENT	EPL01	External Plaster
CODE		TECHNICAL ELEMENT CLASS	C.V.01	Opaque envelope
	C.V.01.01.03.01-EPL01-S1	TECHNICAL ELEMENT	C.V.01.01	External vertical walls
NAME		TYPOLOGY	C.V.01.01.03	External finishing
	FORM 1-External Plaster	MATERIALE	C.V.01.01.03.01	Plaster o masonry
		ASL (Actual Service Life)	28	

SERVICE LIFE INDEX			
	ASL≤RSL	D+=	
	ASL>RSL	D-=	0.893
DEGRADATION INDEX		A_C=	0.984
	minor	A_{Cminor}=	0.889
	medium	$A_{Cmedium}$=	
	serious	$A_{Cserious}$=	1.000

ANOMALIES

TYPOLOGY	NAME	DESCRIPTION	PRESENCE (Y/N)	EVALUATION PARAMETERS	
				TO BE EVALUATED	EXTENSION
MINORS anomalies that compromise only the plaster aspect and not its function	Color change	Change of one or more parameters which define the color (tint, clarity, saturation), discoloration of the finish, oxidation and dulling of the surface (on anodized aluminum), rust stains and permanent stains of cement and plaster.	Y	Visibility of the alteration, changing in the britness color.	high
	Superficial deposits	Accumulation of urban atmospheric dust or of other foreign material, of variable thickness, inconsistent and little adherent to the surface of the coating.	N	Nature, consistence and visibility of the deposits.	

Figure 2 : Extract of a diagnostic form.

The results of the assessment, both for building component families and for the whole building, are listed in Figure 3.

RESIDENTIAL BUILDING

#	CODE	NAME	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
04	C.V.O	Opaque envelope	5	20.41%			19.14%	22 on 90
05	C.V.T	Transparent envelope	8	12.12%	10.10%	5.20%	9.34%	44 on 105
06	C.O.I	Slab on ground	1	3.83%	0.00%	1.92%	3.52%	3 on 13
09	PI.V	Invernal vertical partition	5	22.49%	0.00%	11.71%	17.97%	26 on 52
10	PI.O	Invernal horizontal partition	4	16.89%	0.00%	10.32%	16.47%	9 on 66
11	PE.V	External vertical partition	1	2.18%	0.00%	1.99%	1.77%	7 on 20
12	PE.O	External horizontal partition	2	4.77%	0.00%	2.18%	2.55%	17 on 27
15	IFS.E	Electric plant	4	13.58%	10.41%	13.58%	13.49%	3 on 22
17	IFS.TR	Lift plant	2	3.73%	0.00%	2.49%	3.45%	2 on 12
		TOTAL	32	100.00%	20.51%	49.39%	87.70%	133 on 407

Figure 3 : Technical efficiency index, residential building in Milan.

The grey lines mean that the corresponding building components families have not been assessed. As shown by the results (D^+, D^- and A) the building seems to be old but in a good conservation state; not too many components went beyond their RSL and the anomalies have limited extension and refer to minor damages, fixable without a great effort and not influencing the building use.

For this case study it is also possible to combine the technical efficiency with the document one [9, 10]. The indexes for this case study are graphically displayed in Figure 4.

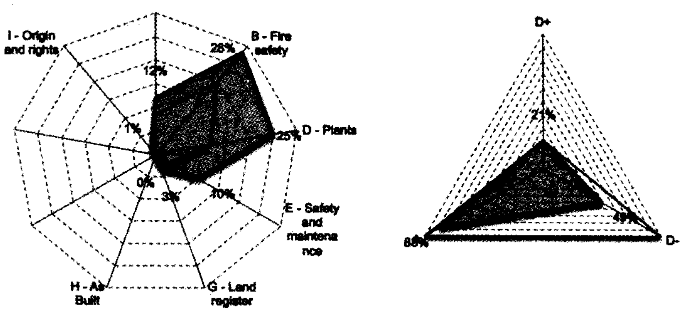


Figure 4 : Documents and technical efficiency graphical output for a residential building in Milan.

The whole building efficiency index is just the average of the two main indexes, in this case:

$$I_{BldEff} = \frac{I_{TechEff} + I_{DocEff}}{2} = \frac{78.64\% + 61.86\%}{2} \approx 70\% \qquad [12]$$

The efficiency indexes for building, families of components and components are a detailed picture of the building and they can give information on it to both non technicians (building owners, users, investors, ...) and technicians (architects, consultants , building managers, ...). As instance, the graphical output displayed in Figure 5 is one of the many ways to present the results in a less technical way, easier to understand than a detailed report, which goes more in depth. Anyway, detailed report and synthetic indexes are the two complementary parts necessary to give to stakeholders an accurate building description.

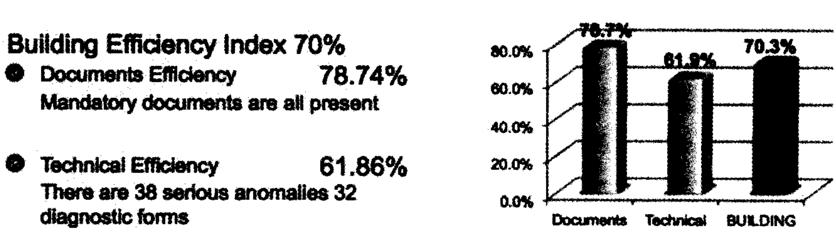


Figure 5 : Building Efficiency Index.

Residential Building in Rome

The second case study presented is a high quality three storeys building in Rome built in 1890 as a dwelling and now used as an office building. Figure 6 shows the main façade of the building and Figure 7 shows efficiency indexes for component families of this case study.

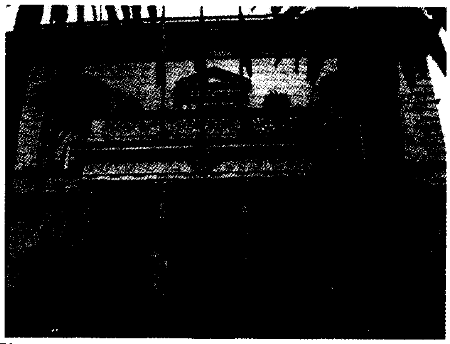


Figure 6 : Residential building in Rome.

RESIDENTIAL BUILDING IN ROME

#	CODE	NAME	NUMBER OF FORMS	WEIGHT	D'	[illegible]	[illegible]	[illegible]
01	S.F	Foundations	3	2.87%	1.22%	1.40%	2.86%	1 on 48
02	S.C	Retains structures	1	2.87%	2.29%	2.87%	2.87%	0 on 20
03	S.E	Elevation struvtures	11	20.33%	15.57%	9.92%	20.23%	5 on 132
04	C.V.O	Opaque envelope	4	10.27%			10.19%	3 on 67
05	C.V.T	Transparent envelope	7	6.10%	3.25%	1.16%	5.87%	13 on 77
06	C.O.I	Slab on ground	5	1.93%	1.34%	1.93%	1.92%	6 on 75
07	C.OSA	Slab on open spaces	4	0.78%	0.56%	0.36%	0.65%	14 on 60
08	C.S	Roof	4	5.27%	3.93%	2.28%	5.11%	5 on 56
09	PI.V	Invernal vertical partition	13	11.31%	6.92%	2.76%	11.26%	7 on 129
10	PI.O	Invernal horizontal partition	16	8.50%	6.06%	2.99%	8.40%	10 on 217
11	PE.V	External vertical partition	7	1.09%	0.52%	0.29%	1.09%	2 on 75
13	IFS.IC	HVAC	17	13.24%	7.42%	13.24%	13.19%	7 on 127
14	IFS.IDS	Water and sanitary plant	6	6.93%	4.24%	6.93%	6.93%	0 on 35
15	IFS.E	Electric plant	20	6.83%	3.83%	6.83%	6.83%	0 on 97
16	IFS.SL	Sewer plant	13	1.41%	0.89%	1.41%	1.41%	0 on 67
18	IFS.A	Fire plant	4	0.26%	0.13%	0.26%	0.26%	0 on 20
		TOTAL	135	100.00%	58.19%	54.63%	99.07%	73 on 1300

Figure 7 : Technical efficiency indexes for building component families.

This building seems to be in a very good conservation state and without relevant anomalies because a complete refurbishment has been made 10 years ago. Although some components seem to be quite old (the D' index is low), they have not been replaced because they have only few anomalies and are still fulfilling, in owner perspective, their function. An upgrade of some of them could be evaluated in case of another refurbishment, remembering obviously that it is a building with an historical value to be preserved.

N. of technological units	16
N. of forms	135
N. of components with D+	105
N. of components with D-	28
Anomalies detected	73 on 1300
Technical efficiency	69.14%

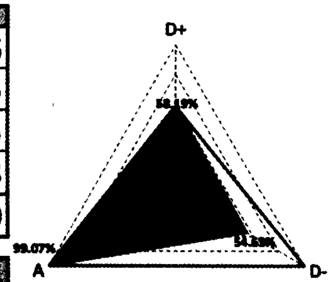


Figure 8 : Technical Efficiency Index.

The results of the assessment, made by CNPI, is showed in Figure 8 with the graph of the three indexes of the building (D^+, D^- and A); the table on the left side of the figure tells us the number of building component families assessed (16), the number of components analysed and, among these, how many have already gone beyond their reference service life (28).

Conclusion

The condition assessment procedure here presented and its main output, the technical efficiency index, has proven to be reliable, easy-to-use and fast. Moreover, it can give information understandable by non-technician stakeholders (the efficiency indexes of the building) but useful to technicians (component families index and information about anomalies) in different stages of the building service life. The two case studies also showed that this tool can be adapted to different building types.

The efficiency index is the base point for further research on refurbishment potential of the built environment, the next questions that are to be answered are: 'how much do I have to pay to repair all the anomalies that this tool says are serious?'; 'are there any maintenance operation that has to be done before then other?'; 'Is it possible to find a priority for maintenance operations?'.

References

1. Ahluwalia, S.S. – *A Framework for Efficient Condition Assessment of the Building Infrastructure*, University of Waterloo, (2008).
2. ASCE 30-00 – Guideline for Condition Assessment of the Building Envelope.
3. Ezovski, D. – *The Value of Property Condition Assessment in Commercial Real Estate Lending*, Article on The RMA Journal, (2009), pp.46-48.

4. Queensland Government – *Maintenance Management Framework – Building Condition Assessment*, Department of Housing and Public Works, (2011).

5. Straub, A. – *Using a Condition-Dependent Approach to Maintenance to Control Costs and Performances*, in Journal of Facilities Management, Vol. 1, (2002), pp.380-395.

6. Zimring, C. – *Facility Performance Evaluation (FPE), WBDG Whole Building Design Guide*, a program of the National Institute of Building Sciences, (2010).

7. Flourentzou, F.; Brandt, E.; Wetzel, C. – *MEDIC – A Method for Prediction of Residual Service Life and Refurbishment Investment Budgets*, in Journal of Energy and Buildings, Vol. 31, Issue 2, (2000), pp.167-170.

8. ISO 15686-8:2008 – Building and Constructed Assets – Service-Life Planning – Part 8: Reference Service Life and Service-Life Estimation.

9. Dejaco, M.C.; Re Cecconi F.; Maltese S. – *Real Estate Performance Assessment for Sustainable Refurbishment*, Proceeding of the World Building Congress 2013 WBC13, Brisbane, 2013.

10. Dejaco, M.C.; Re Cecconi, F.; Maltese, S. – *Logbook's Dynamic Structure in Building Process*, Proceedings of the XXXIX World Housing Congress, Milano, September 17-20, 2013.