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A multi-criteria framework for decision process in retrofit optioneering through interactive data flow

Fulvio Re Cecconi[a,]*, Lavinia C. Tagliabue[b], Sebastiano Maltese[a], Martina Zuccaro[a]

[a]*Politecnico di Milano Department of Architecture, Built Environment and Construction Engineering, via Ponzio 31, Milano 20133, Italy*
[b]*University of Brescia, Department of Civil, Environmental, Architectural Engineering and Mathematics, Via Branze 42, Brescia 25123, Italy*

Abstract

Aim of this research is to deliver a system of procedures and instruments that allows comparing different scenarios of restoration and retrofit of existing buildings applicable each time a relevant decision about the asset has to be made. The system developed takes advantages of Building Information Modeling (BIM) and Analytical Hierarchy Process (AHP), thus to focus on main clients' needs. Decisions about real estate assets are frequently made by managers with incomplete and scattered data, not sufficient to fully support the decision making process. Using a BIM model as a central repository of information could strongly support to compare objectively different scenarios and consequently to decide the application of a multi-criteria matrix involving management, energy, economic and social issues. BIM and BEM (Building Energy Modelling) techniques have a wide potential and analysis capabilities; however, they are often adopted without an integrated framework, causing missing performances and costs overrun. The result is a system enabling to analyze the asset, to produce BIM and BEM models ready to include life cycle data, to evaluate feasible alternatives and scenarios and to extract relevant performance indicators for decision makers' support. An existing office building in Milan representing an awkward field for intervention is the case study for the system application. While the tools and software adopted are commonly used, the system of procedures developed by the authors can be considered as an ensemble of workflows otherwise typically used independently. Using them together enhance the decision process providing data on which to set up a strategic plan of the refurbishment considering costs, continuity in occupancy and energy efficiency.

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Keywords: Refurbishment; multi-criteria decision making; LCC; BIM; BEM.

* Corresponding author. Tel.: +39 02 2399 6052; fax: +39 02 2399 6020.
E-mail address: fulvio.rececconi@polimi.it

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1. Introduction

In Europe around 40% of energy consumption, approximately 11,530 TWh is attributable to the residential and commercial sector [1]. The total primary energy consumption of the buildings belonging to these sectors in Italy shows, in comparison with other EU Countries, one of the higher values. Considering the buildings distribution by intended use, at national level, the average percentage of residential buildings is 87% of the total, while different uses (e.g. hotels, offices, commerce and industry, communications and transport and other uses) represent 6% and the unused buildings represent a further 6%.

Based on National Census data, in Italy there are over twelve million buildings (Fig. 1). More than 50% dates before 1970, which means before the first National Law [2] on energy efficiency was ever adopted. The first Italian law about energy efficiency in buildings dates 1976 although it was mainly ignored as similarly occurred with the most famous L.10/91 [3]. Italy is not an exception, in other country of the European Union most of the buildings are old and characterized by low energy performance and lacking by the comfort and indoor quality [4].

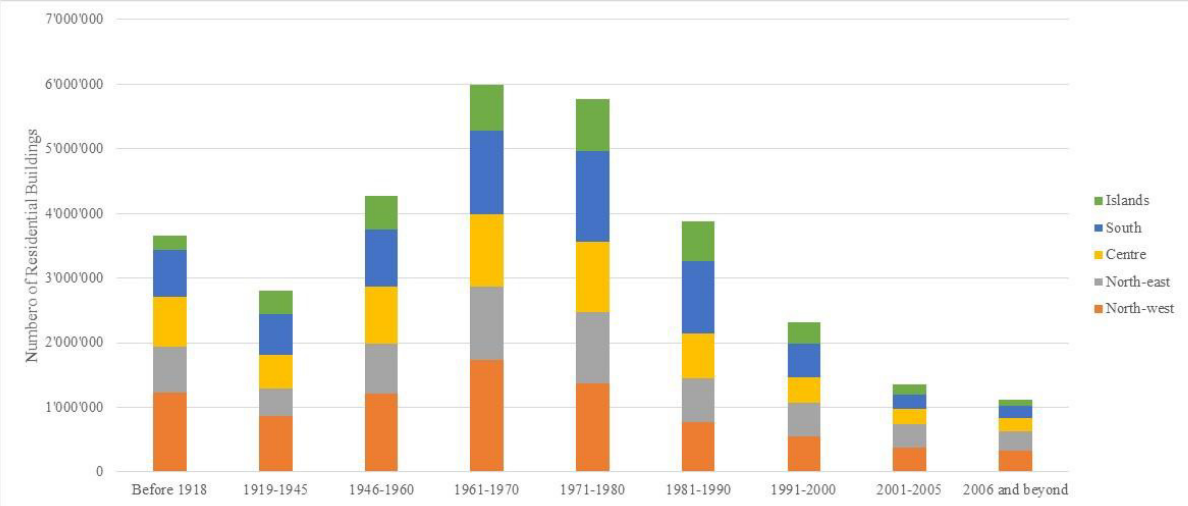

Fig. 1. Construction years of residential building in Italy (data from 2011 National Census).

Old building stocks are facing with regulatory practices shifting toward reductions in energy use, with new users' needs and, most of the times, with the request for improved economic performance. These building stocks are rarely replaced with new and more efficient buildings; in fact, the replacement rate of existing buildings by new buildings is only around 1.0–3.0% per annum [5], thus energy retrofit of existing building is more or less the privileged way to enhance energy efficiency of high-energy consumer assets.

Among existing buildings, office ones have one of the peak levels of energy consumption, which can vary between 100 and 1000 kWh/m^2 year. At national level, an energy audit performed on office buildings in different climatic zones of the territory [6] identified the average values of the total specific consumption of electrical energy and primary energy for heating only.

Cross-checking consumption data for each climate area with the percentages of office buildings per location can be identified a national average consumption for heating of around 80 kWh/m^2 per year. The average specific fuel consumption of 72% of the office buildings, which are located in climatic zones D and E, is about 95 kWh/m^2 year, excluding the quota of electricity required for air treatment. The average energy consumption for buildings located in the North of the country and in other cold climates is about 100 kWh/m^2 (referred to heating only).

The specific primary energy consumption for electricity and heating for offices located in Italy in the different climate zone [7] are reported in the following Table 1. The climate zones are related to the value of Degree Days (HDD') defined as the integral of the differences of the outdoor air temperature and a base temperature (commonly 18°C) above which a building needs no heating.

Table 1. Specific electricity and primary energy consumption for Italian climate zone for office buildings.

Climate zone	Degree Days (HDD')	Specific consumption of electricity [kWh/m^2 year]	Specific consumption of primary energy for heating [kWh/m^2 year]
A	DD > 600	155	2.9
B	600 > DD > 900	156	28.8
C	900 > DD > 1400	139	57.6
D	1400 > DD > 2100	125	86.4
E	2100 > DD > 3000	90	104.6
F	DD > 3000	52	221.8

For the total absorption of electric power, it is difficult to make a climatic correction, as the part of the power consumption attributable to the indoor climate in the different zones is difficult to estimate. However, considering that almost 80% of the buildings located in the climate zone F does not have a cooling system, and that only 5% is equipped with an electric heating system, it can be assumed that the 52 kWh_e/m^2 year recorded in that area are related to unavoidable electrical equipment (i.e. lighting, electrical equipment, etc.). For this reason, an analysis on several case studies in northern Europe (i.e. Sweden, Denmark, Finland, Norway) identified an average electricity consumption for office use equipment of about 25 kWh_e/m^2 year, to which has to be added the contribution for artificial lighting.

At the national level, it can consequently be presumed a consumption related to the electrical components, required of the offices, around 45-55 kWh_e/m^2 year, while the part due to cooling in the summer period can be considered variable between 40 kWh_e/m^2 year for and the climate zone E and 115 kWh_e/m^2 year for climate zone A [8].

Starting from the literature estimation [9] it is possible to calculate the potential reduction of energy consumption for the tertiary sector, retrofitting the buildings to current mandatory requirements, as equal to about 30%.

In order to make buildings more energy-efficient, a wide-ranging set of energy efficiency measures has been developed. Nevertheless, extensive studies [10] show that:

a) the selection of energy saving building components takes place based on use of these components by architects or consultants in current practices or individual earlier projects, or based on the use of these components in reference projects;
b) virtually, there is not a practice of energy optioneering to selection of saving measures based on an equivalent comparison of the design variants performance on the project building.

For this reason, a multi-criteria framework to support energy retrofit decision could be beneficial both for the planning of the interventions phase both as a guideline in the design phase and during the life cycle of the building to promote a progressive improvement according to developing regulation and standards.

2. Multi-criteria framework

A multi-criteria framework has been used as methodological approach to refurbishment choice process to enhance the decision process and reduce the uncertainties and inconsistencies of uninformed and approximate choices. The field of study (section 3) is awkward due to the aesthetic value and quality of the building and owners were aware of the sensitivity of the modern architecture issue.

Multi-Criteria Decision Making (MCDM) refers to taking decisions in case of multiple, usually conflicting, criteria [11]. Widespread shared definitions [12] classify them as follows:

a) Multiple Attribute Decision Making (MADM), with discrete, usually limited, number of pre-specified alternatives, requiring inter and intra-attribute comparisons, involving implicit or explicit tradeoffs;
b) Multiple Objective Decision Making (MODM), with decision variable values to be determined in a continuous or integer domain, of infinite or large number of choices, to best satisfy the decision maker constraints, preferences or priorities.

Although MADM methods may be widely diverse [13], many of them have certain aspects in common [14], such as the notions of alternatives, and attributes (or criteria, goals) as here described [15]:

- Alternatives represent the different choices of action available to the decision maker. Usually, the set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, prioritized and eventually ranked.
- Attributes, also referred to as goals or decision criteria, represent the different dimensions from which the alternatives can be viewed. Since different attributes represent different dimensions of the alternatives, they may conflict with each other and may be associated with different units.

2.1. Analytic Hierarchy Process (AHP)

Most of the MADM methods require that the attributes be assigned weights of importance, this can be done with a coupled comparison system such as the Analytic Hierarchy Process (AHP) [16]. In the present research, this system has been selected to deal with the relative importance of the criteria. AHP has been selected because it is simple, robust, repeatable, objective, commonly recognized as valid and eventually it has been used in many different researches in the construction industry [17], with further interesting connections [18][19][20] with TOPSIS (a multi-criteria selection method) and fuzzy logic [17].

AHP is based on the coupled comparison of the various attributes under analysis to assign weights reflecting their relative importance. Even if it is a simple process, methodologically it is robust and effective to deal with real problems [21][22][23]. AHP has been used in many cases [24][25] in association with the Delphi Method [26][27][28], which was devised in order to obtain the most reliable opinion consensus [29][30] of a group of experts by subjecting them to a series of questionnaires in depth spaced out with controlled opinion feedback [31][32].

2.2. Multiple Attribute Decision Making (MADM)

The MCDM, together with the AHP, has been used to first evaluate the criteria importance and consequently to pick the most suitable option (Fig. 2), in which the whole process of the present research is outlined. The method starts from a sequence of interviews with the stakeholders aimed to define the criteria on which the refurbishment options should be measured. A major cause of poor performance of construction projects is reported to be the inadequate consideration of stakeholders' requirements in the early design stage [33].

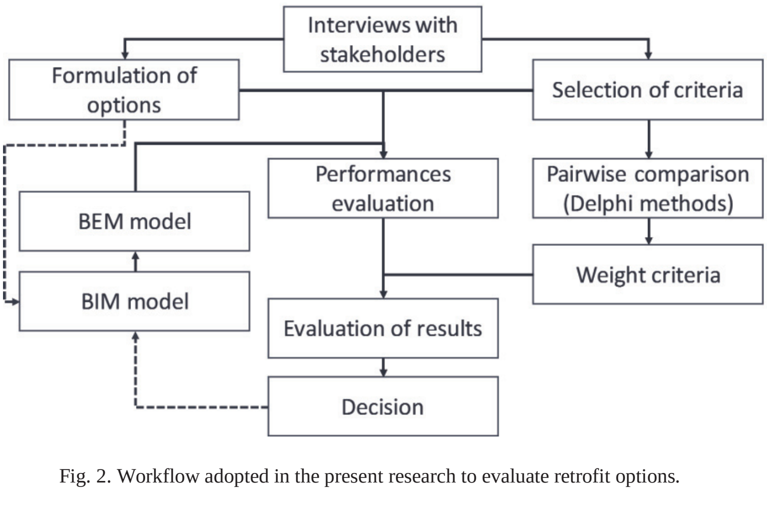

Fig. 2. Workflow adopted in the present research to evaluate retrofit options.

The decision accordingly to which the selected retrofit technology (or measure) should be adopted for a specific project is a multi-objective optimization problem subject with many constraints and limitations [34], such as detailed building features, total budget availability, project target, building services types and efficiency, building materials, etc. Financial benefit is not the single criteria for the selection of the retrofit technologies. The optimal solution is a trade-off among a range of energy and non-energy related factors, such as economic, technical, environmental, regulations, social, construction, etc.

Once the criteria have been selected two or more refurbishment options can be defined. Studies on the topic [35] pointed out, in case a small number of refurbishment options have been defined, there is no guarantee that the solution finally approved is the best one from the decision maker's perspective. On the opposite case, when a large number of solutions are defined, the required evaluation and selection process may become extremely difficult to handle. Furthermore, in the present research, the selection process has also been carried out in close collaboration with the owner and managers involved in building operation and maintenance in order to optimize the number of options to be analyzed.

The performances evaluation of the designated refurbishment options is always a time-consuming step of the procedure and it is not possible to take up additional time for the retrofit planning [36]. The whole performances evaluation phase has taken advantages by using BIM models [37], employed for a rapid and reliable Quantity Take-Off (QTO), for work planning, for maximizing the located surface even during major refurbishment works and as a data repository for the BEM models used to compute the energy performances of the refurbishment options.

For the pairwise comparisons of the selection criteria, each criterion is matched one-on-one with each of the other criterion. The relative importance values are determined on a scale ranging 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; which means:

$$a_{ij} = \frac{1}{a_{ji}}$$

where a_{ij} denotes the importance of the i^{th} criterion compared with the j^{th} criterion. Then, the eigenvector method is employed to obtain the local priority vectors for the coupled comparison matrix (i.e. the weight for each criterion). The consistency of a pairwise comparison can be tested applying 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 [16].

Eventually, a weighted mean of the evaluated performance gives a unique performance indicator for the refurbishment options; this shows the best refurbishment option to which orient the final decision.

3. Case study

The case study of this research is an office building located in Milan, namely the "Palazzo Savoia Assicurazioni e Riassicurazioni" in Via San Virgilio (Fig. 3a) built in 1971, designed by Gio Ponti, Antonio Fornaroli, Alberto Rosselli and now leased to an insurance company. Gio Ponti is a famous Italian architect, and the building is included in the historical archive of modern architecture in Milan, Italy. Major maintenance operations have never been undertaken on the building (Fig. 3b): façade cladding, windows and many other building components are old or even original presenting clear decay evidences. Because of the lack of maintenance, the building shows many pathologies (Fig. 3c), some of these involving safety hazard for building users, and, eventually, the owner decided to investigate the best refurbishment project that could be activated on the building adopting the presented advanced selection methodology.

3.1. Retrofit projects

By a series of interview with the owner of the building and with the asset management company in charge of its operation and maintenance, three types of refurbishment strategists were identified and compared to a baseline, the so far followed maintenance strategy, i.e. no maintenance at all (here entitled refurbishment Project 1):

1. No maintenance intervention on the building.
2. Safety improvement: replacement of detached façade tiles with new elements, without touching any other element.

3. Complete replacement of façade tiles and aluminum windows improving thermal properties of the transparent surfaces.
4. Improvement of thermal performance of the façade with an External Thermal Insulation Composite Systems (ETICS) and replacement of all aluminum windows.

In any case the new tiles would look alike the old ones that were specifically designed for this project by Gio Ponti and in the refurbishment Project 3 and Project 4 the new aluminum windows would satisfy the minimum thermal performance requirements defined by the national energy regulation.

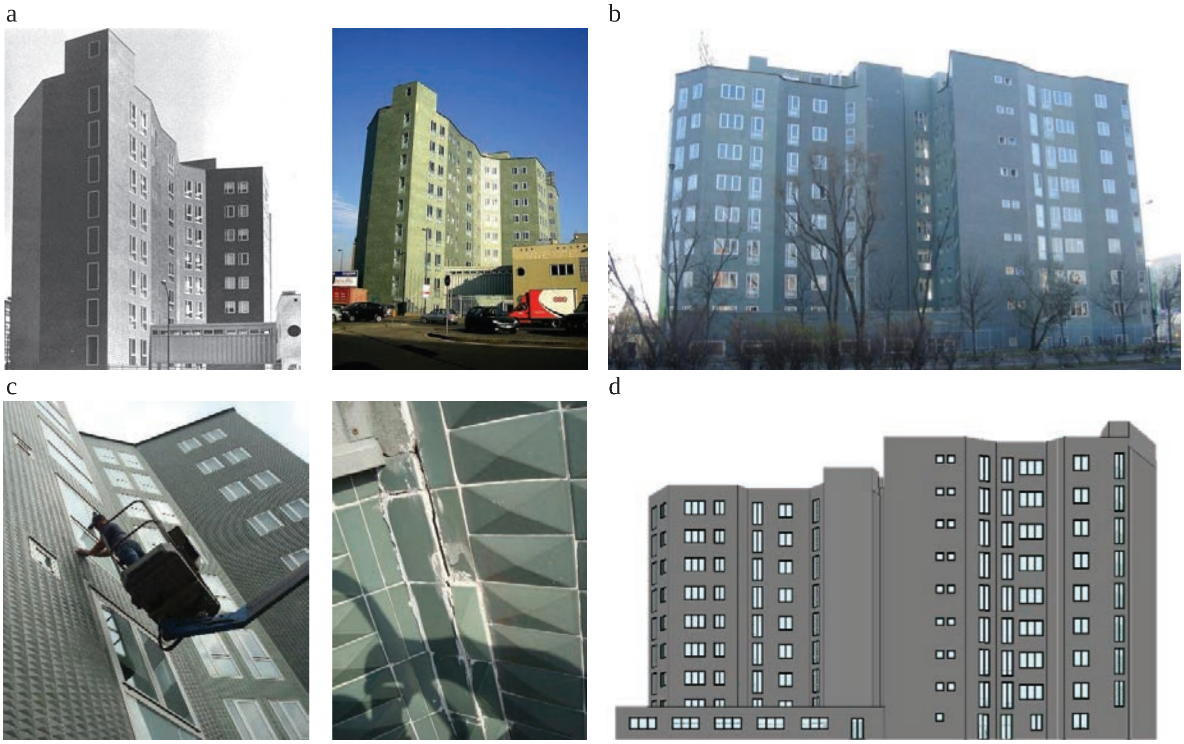

Fig. 3. Historical picture of the Palazzo Savoia Assicurazioni e Riassicurazioni office building (a) and today view; the building had a strong need of refurbishment (c) and the analysis has been base on a BIM model (d) to compute energy needs and quantities.

3.2. Criteria

Thus, the criteria to select the best refurbishment project were discussed in the interviews with the stakeholders, owner and Management Company agreed to use the following three as decision criteria:

a) Life Cycle Cost (LCC) computed over a period of 50 years and expressed as Present Value (PV) Euro (i.e. life cycle costs discounted to present day).
b) Space Availability to rent over 50 years measured in terms of money lost due to the lower rent.
c) Aesthetic of the building, measured with a qualitative judgment, because always the aesthetic of the building is related to its value and to the rent rate.

In order to speed up the performance evaluation of the four refurbishment projects according to the selected criteria, a BIM model (Fig. 3d) of the building was created and used both for Quantity Take-Off and as the starting point for a BEM model used for estimating energy demands of the building in the four refurbishment scenarios.

Façade tiles are very peculiar and no similar model could be found on the market, consequently, to compute LCC, in particular Installation (I) and Replacement (R_{epl}) costs, a sample has been sent to a panel of manufactures and the best prices was adopted as driven criteria to choose the product.

4. Results

4.1. Life Cycle Cost and Space Availability

The discount rate applied is the same for each refurbishment project; inflation rate was not take into account in the calculation of costs discount. Definitely, energy costs, computed via BIM to BEM model and dynamic simulation are lower in project 4 since it includes an efficient energy retrofit of the whole façade installing an External Thermal Insulation Composite System (ETICS), while project 3, where thermal performance improved windows substitute aluminium windows, reports a slight upgrading in energy demands in comparison with project 2. The calculation of the performance related to the availability of space criteria has been based on the losses in rental income estimated on the rent nowadays remunerated by the tenant and the extension of surface (m^2) that, during the 50 years, couldn't be rented because of construction and maintenance works on the façade (project 4: ETICS installation and windows replacement). Only refurbishment Project 3 and Project 4 have a lower income due to a reduced rented surface; the economic loss amounts to 146'601.63 Euro (PV) for refurbishment Project 3) and 157'073.17 Euro (PV) for Project 4). The losses have been discounted with the same discount rate used for the LCC estimation (Table 2).

Table 2. Life Cycle Costs associated with the four projects of refurbishment (50 years period; Present Value Euro)

Refurbishment project	I (*Euro*)	R_{epl} (*Euro*)	E (*Euro*)	OM&R (*Euro*)	LCC (*Euro*)
Project 1	0	0	1'668'000	503'000	2'171'000
Project 2	275'000	1'002'000	1'668'000	520'000	3'465'000
Project 3	840'000	820'000	1'636'000	498'000	3'794'000
Project 4	1'025'000	1'000'000	1'539'000	503'000	4'067'000

4.2. Aesthetic

Finally, the aesthetic criterion has been evaluated by a qualitative judgment of the refurbishments projects: 1) worst aesthetic; 5) best aesthetic, integer intermediate values allowed. Refurbishment Project 1 and Project 2 would not modify the aesthetic value of the building; the old tiles will remain untouched nevertheless for the detached portions. Refurbishment Project 3 and Project 4 will give a building a complete new façade and, as a consequence, an improved aesthetic aspect. According to the described concern on aesthetics both the owner and the asset management company in charge agreed to propose a value equal to 1 for the aesthetic performance in Project 1 and Project 2 and gave a value of 5 point to Project 3 and Project 4.

4.3. Refurbishment Projects comparison

Criteria whose performances are computed with different units (LCC and space availability are computed in PV Euro, aesthetic is compute with a qualitative judgement) cannot be easily fit into a multi-criteria evaluation. Before employ the evaluated performances, they had to be transformed in a comparable scale or units of measurement. To do that both LCC and space availability where translated into a dimensionless quantities having the same minimum value (1) and maximum value (5) of the aesthetic performance using these equations:

$$LCC_i[Dimensionless] = 5 - 4 \times \frac{LCC_i[Euro] - \min(LCC\ [Euro])}{\max(LCC\ [Euro]) - \min(LCC\ [Euro])} \quad (1)$$

$$Availability_i[Dimensionless] = 5 - 4 \times \frac{Availability_i[Euro] - \min(Availability\ [Euro])}{\max(Availability\ [Euro]) - \min(Availability\ [Euro])} \quad (2)$$

The following Fig. shows the comparison of the four (three plus the base line) refurbishment projects. The comparison is based on the performance measured in terms of the selected criteria. It can be noted that refurbishment Project 2 (changing merely the detached façade tiles) (Fig. b), presenting the lowest investment cost, shows a much better performance in comparison with Project 3 (Fig. c) and Project 4 (Fig. d) in terms of LCC and Space availability while these overcome Project 2 in the aesthetic performance evaluation.

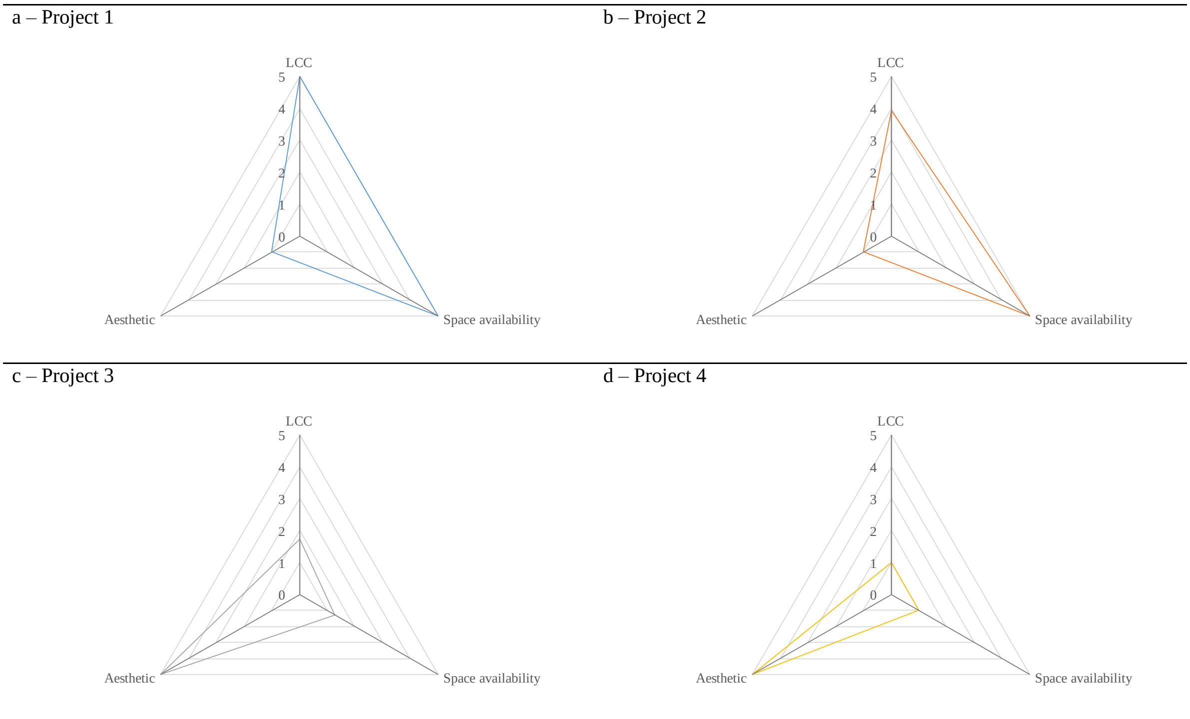

Fig. 4. Performance evaluation of (a) project 1, (b) project 2, (c) project 3, and (d) project 4

The three evaluation criteria may have a different significance according to the final decision maker of the refurbishment project. Twenty experts working in the field of facility and property management were involved in the discussion group of the present case study, to define a set of weight for the three criteria in order to sum the performance evaluation results up in a single key performance indicator aimed to support the decision making process.

In order to aggregate the opinions of the different experts, the discussion was facilitated using the Delphi Method [23][23]. During each round of the Delphi method, experts were asked to fill a pairwise comparison based on the AHP technique [16] and to revise their earlier answers after the replies of the other members of their panel. The outcomes of this discussion have been the following weights: LCC 61%; Space availability 19%; Aesthetic 20%. The pairwise comparison was quite successful because the matrix with experts' judgements has a consistency index CI= 0.01 and, consequently, a consistency ratio CR=2%, much lower than the maximum acceptable limit found in literature (10%). The three criteria aggregated into a final performance indicator computing their weighted mean are shown in Table 3.

Project 3 and Project 4 are disadvantaged by the extremely high initial investment cost. In fact, the energy saving defined by the energy retrofit not enough to give profitability to Project 3 and Project 4. According to the experts involved in the decision making process, the importance of LCC is higher than the criteria of Space Availability and Aesthetic put together (LCC weight is greater than the sum of Space Availability and Aesthetic weights).

It is worthy to note that, if safety was not a matter, no refurbishment project can be judged better than no intervention (Project 1) according to the chosen evaluation criteria (Fig.).

Table 3. Results of refurbishment project comparison by a single comprehensive key performance indicator.

Type of refurbishment project	Performance indicator
Project 1	4.2
Project 2	3.55
Project 3	2.29
Project 4	1.8

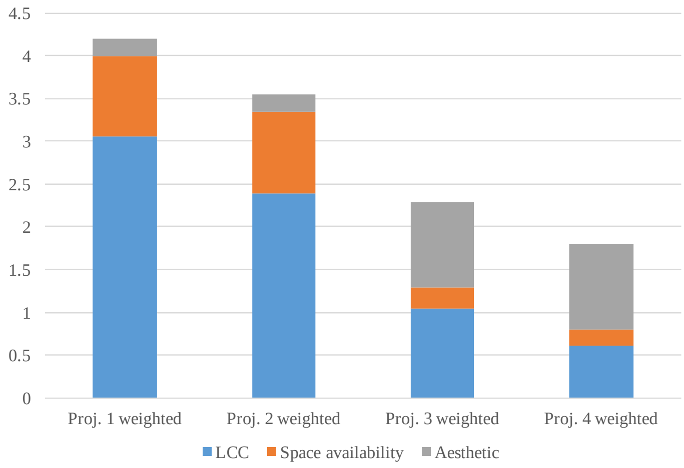

Fig. 5. Weighted results of the performance of the four refurbishment projects.

5. Discussion and conclusions

The results obtained in the case study may yield to the conclusion that, quoting Mies van der Rohe, less is more, i.e. to do less in terms of maintenance operation/refurbishment is more profitable in terms of asset management. Though these results are strongly influenced by the relative importance of the criteria, namely by the fact that the LCC weight is bigger than the sum of the weights of the other two criteria. Maybe interviewing a different panel of experts or widening it including not only facility manager but furthermore users of the building would yield to different relative weights where the importance of the aesthetic of the building could be greater. Moreover, including new criteria such as, for example, the carbon footprint of the building or any other attribute relate to sustainability, could change dramatically the results and energy saving project as Project 3 and Project 4 could be the best refurbishment choice. The research proved that multi-criteria decision methods can support decision makers facing with evaluation of alternatives by taking into account multiple criteria in an explicit manner because they provide a structured and transparent approach to identify a preferred alternative by clear consideration of the relative importance of the different criteria and the performance of the alternatives on the criteria. Coupling MCDM with a BIM based optioneering process proved to be convenient for speeding up the performance assessment process as shown in the case study where the BIM model was adopted: a) for quantity take-off; b) as the main source of information for the BEM model; and c) to store performance evaluation results for further use. Further steps of this research will be focused on adding attributes to the MCDM in order to take into account environmental issues and on reaching a wider expert panel in order to collect opinions from people with different backgrounds to include more related aspects.

References

[1] Directive 2010/31/EU of The European Parliament and of the Council of 19 May 2010 on the energy performance in buildings (recast), Journal of the European Union L. 153/13, 18.6.2010.

[2] Legge ordinaria del Parlamento n° 373/76 "Norme per il contenimento del consumo energetico per usi termici negli edifici", pubblicata sulla Gazzetta Ufficiale Italiana n° 148 del 07/06/1976.

[3] Legge 9 gennaio 1991, n. 10, in materia di "Norme per l'attuazione del Piano energetico nazionale in materia di uso razionale dell'energia, di risparmio energetico e di sviluppo delle fonti rinnovabili di energia".

[4] C.A. Balaras, et al., Potential for energy conservation in apartment buildings, Energy & Buildings 31 (2), 2000, 143–154.

[5] Z. Ma, P. Cooper, D. Daly, L. Ledo, Existing building retrofits: method- ology and state-of-the-art, Energy and Buildings 55 (0), 2012, 889–902.

[6] ENEA, Caratterizzazione dei consumi energetici nazionali delle strutture ad uso ufficio, (2009), www.enea.it/enea_paese.

[7] D.P.R. 26 agosto 1993, n. 412 , Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della L. 9 gennaio 1991, n. 10, Gazz. Uff. 14 ottobre 1993, n. 242, S.O.

[8] ENEA, Rapporto energia e ambiente 2007. Analisi e scenari, Ente per le Nuove tecnologie, l'Energia e l'Ambiente, Roma, 2008.

[9] ENEA, Valutazione dei consumi nell'edilizia esistente e benchmark mediante codici semplificati: analisi di edifici residenziali, Roma 2008.

[10] P. de Wildea, M. van der Voordenb, Providing computational support for the selection of energy saving building components, Energy and Buildings, Volume 36, Issue 8, August 2004, Pages 749–758

[11] Y. Shao, P. Geyer, W. Lang, Integrating requirement analysis and multi-objective optimization for office building energy retrofit strategies, Energy and Buildings, Volume 82, October 2014, Pages 356-368.

[12] C. L. Hwang, K. Yoon, Multiple Attribute Decision Making Methods and Applications, Springer-Verlag, 1981.

[13] S. H. Zanakis, A. Solomon, N. Wishart, S. Dublish, Multi-attribute decision making: A simulation comparison of select methods, European Journal of Operational Research, Volume 107, 1998, Pages 507-529.

[14] S.J. Chen, C.L. Hwang, Fuzzy Multiple Attribute Decision Making: Methods and Applications, Lecture Notes in Economics and Mathematical Systems, No. 375, Sringer-Verlag, Berlin, Germany, 1992.

[15] E. Triantaphyllou, B. Shu, S. Nieto Sanchez, and T. Ray, Multi-Criteria Decision Making: An Operations Research Approach, Encyclopedia of Electrical and Electronics Engineering, (J.G. Webster, Ed.), John Wiley & Sons, New York, NY, Vol. 15, pp. 175-186, 1998.

[16] T. Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, McGraw-Hill, New York, 1980.

[17] G. Zheng, Y. Jing, H. Huang, G. Shi, X. Zhang, Developing a fuzzy analytic hierarchical process model for building energy conservation assessment, J. Renewable energy, Volume 35, 2010, Pages 78-87.

[18] P. Lai, A. Potter, M. Beynon, A. Beresford, Evaluating the efficiency performance of airports using an integrated AHP/DEA-AR technique, J. Transport Policy, Volume 42, 2015, Pages 75-85.

[19] F.R. Lima Junior, L. Osiro, L.C.R. Carpinetti, A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection, J. Applied Soft Computing, Volume 21, 2014, Pages 194-209.

[20] S. Vinodh, M. Prasanna, N. Hari Prakash, Integrated Fuzzy AHP–TOPSIS for selecting the best plastic recycling method: A case study, J. Applied Mathematical Modelling, Volume 38 Number 19-20, 2014, Pages 4662–4672.

[21] A.C. Brent, D.E.C. Rogers, T.S.M. Ramabitsa-Siimane, M.B. Rohwer, Application of the analytical hierarchy process to establish health care waste management systems that minimize infection risks in developing countries, European Journal of Operational Research, Volume 181, 2007, Pages 403-424.

[22] N. Bryson, and A. Mobolurin, An action learning evaluation procedure for multiple criteria decision making problems, European Journal of Operational Research, Vol. 96, 1995, pp. 379-386.

[23] J.K.W. Wong, H. Li, Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems, J. Building and Environment, Volume 43, 2008, Pages 108-125.

[24] S. Hsueh, M. Yan, Enhancing Sustainable Community Developments A Multi-criteria Evaluation Model for Energy Efficient Project Selection, International Conference on Energy, Environment and Development - ICEED2010, Energy Procedia, Volume 5, 2011, Pages 135-144

[25] Y. Yang, B. Lia, R. Yao, A method of identifying and weighting indicators of energy efficiency assessment in Chinese residential buildings, Energy Policy, Volume 38, Issue 12, December 2010, Pages 7687–7697

[26] H. A. Linstone ; M. Turoff, Delphi Method: Techniques and Applications, 1975, Addison-Wesley Publishing

[27] S. Hsueh, A Fuzzy Utility-Based Multi-Criteria Model for Evaluating Households' Energy Conservation Performance: A Taiwanese Case Study, Energies 2012, Volume 5, Issue 8, 2818-2834

[28] L. Vidal, F. Marle, J. Bocquet, Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects, Expert Systems with Applications, Volume 38, Issue 5, May 2011, Pages 5388–5405

[29] S. H. Alyami, Y. Rezgui, Sustainable building assessment tool development approach, Sustainable Cities and Society, Volume 5, December 2012, Pages 52–62

[30] K. Liu, S. Hsueh, W. Wu, Y. Chen, A DFuzzy-DAHP Decision-Making Model for Evaluating Energy-Saving Design Strategies for Residential Buildings, Energies 2012, Volume 5 Issue 11, Pages 4462-4480

[31] N. Dalkey, O. Helmer, An Experimental Application of the DELPHI Method to the Use of Experts, Management Science, 1963, Volume 9 Issue3 , pp. 458-467

[32] J. Pill, The Delphi method: Substance, context, a critique and an annotated bibliography, Socio-Economic Planning Sciences, Volume 5, Issue 1, February 1971, Pages 57-71

[33] N.Singhaputtangkul,S.P.Low,A.L.Teo,B.-G.Hwang,Knowledge-baseddecision support system quality function deployment (KBDSS-QFD) tool for assessment of building envelopes, Automation in Construction, 2013, Volume 35, Pages 314–328.

[34] Z. Ma, P. Cooper, D. Daly, L. Ledo, Existing building retrofits: Methodology and state-of-the-art, Energy and Buildings, 2012, Volume 55, Pages 889–902

[35] E Asadia, M. G. da Silva, C. H. Antunesc, L. Diasc, L. Glicksman, Multi-objective optimization for building retrofit: A model using genetic algorithm and artificial neural network and an application, Energy and Buildings, 2014, Volume 81, Pages 444–456

[36] F. Flourentzou, C.-A. Roulet, Elaboration of retrofit scenarios, Energy and Buildings, 2002, Volume 34, Pages 185-192

[37] D. Ilter, E. Ergen, BIM for building refurbishment and maintenance: current status and research directions", Structural Survey, 2015, Vol. 33 Iss 3, pp. 228 – 256