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Methodologies for Supporting Sustainability in Energy and Buildings. The Contribution of Project Economic Evaluation.

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Abstract

The aim of the paper is to highlighting economic-evaluative approaches involved in regulations and policies supporting sustainability in energy and buildings. Attention is given to Directive 2010/31/EU (EPBD recast) and following Commission Delegated Regulation (EU) n.244/2012, which require MS to set minimum energy performance requirements on the cost-optimal level. Focus is placed on ISO 14040:2006, ISO 15686:2008 and ISO 21500:2012, respectively on Life Cycle Assessment, Life Cycle Costing and Project Management. Sustainable Design principles and Life Cycle Thinking approach are assumed. The study aims to support decision making processes, public authorities in planning and in territorial governance, designers, real estate investors.

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Keywords: Economic-environmental sustainability; Project Economic Evaluation; Life Cycle Thinking; Life Cycle Costing; Project Management; Risk Analysis

1. Introduction

This paper is relevant to the current scientific debate on project sustainability. Project sustainability includes:

- the international energy policies framework, and the guidelines laid down in Agenda 20-20-20

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- a multidisciplinary approach that involves disciplines such as Building Physics, Materials Science, Environmental Technology, with special focus on Real Estate Appraisal and Project Economic Evaluation [1]
- recent studies on Architecture Sustainable Design concept [2]
- studies on the real estate market, specifically on the analysis of buildings' energy efficiency as a determinant of asset prices, and on the economic impacts of energy retrofit [3,4]

The aim of the paper is to give a contribution to valorize the methodologies developed in Project Economic Evaluation for supporting sustainability in energy and buildings. Specifically, this work uses the potentiality of the evaluative theories and operative approaches for: orienting designers in selecting the preferable building options from an environmental and economic point of view, from the early design stages; supporting managers in defining coherent policies and strategies for reducing energy consumption, specifically in the case of existing buildings; supporting public authorities in planning and programming activities, through actions to improve buildings' energy performances on the urban scale, including public properties.

The paper refers to the state-of-the-art in economic evaluation of projects theory and practices in Italy, and it considers the international regulatory framework on energy and environmental sustainability in the building context. It considers European experiences and researches related to policies and practices. It orients the operative tools for the economic-financial evaluation and risk analysis of projects, towards a "technological-economic approach". In fact, considering energy-environmental aspects beside the economic-financial ones, it is possible to support a feasibility analysis of a project or part of a project, or processes of option selection, from the early design stages, both in the case of new buildings and in the retrofit of existing ones including cultural heritage. The reasoning proposed focuses on "cost" and "life cycle" concepts, strictly correlated. These are assumed as crucial aspects for the decision making process in the presence of alternative technological options, at different production/construction scales (single material, single component, building systems, entire building) or at different territorial levels (major complex transformation projects scale, district scale, urban scale).

The work attempts to provide a significant contribution in two main directions: providing elements for growing the literature on sustainability in energy and buildings, outlining an overall framework of the evaluative approaches and tools suited to respond to the legislative guidelines; providing insights to jointly develop approaches and methods that usually are applied in separate areas. These two addresses represent, to a certain extent, an original aspect of the work presented.

Section 2 presents the most recent international legislation in the context of the energy sustainability of buildings, highlighting the concepts of cost and life cycle. Section 3 focuses on the cost concepts and their calculation for energy-environmental-economic sustainability, starting from Standards, regulations and methodological guidelines. Section 4 looks at to the approaches deriving from the Life Cycle Thinking approach, such as the Life Cycle Costing approach for economic sustainability and the Life Cycle Assessment for environmental sustainability. The use of both approaches together is also considered. Section 5 presents the Project Management approach, starting from the EU Standard, considering relations with life cycle phases. Attention is given to the potentiality of Cost Control and Cost Risk Analysis, in conjunction with Discounted Cash Flow Analysis, as a tool to support management activities and decision making processes, in the presence of risk and uncertainty components. Finally, section 6 discusses and concludes the paper[†].

2. Regulatory framework for building energy performance and economic-evaluative methodologies

In the European and international context, the recent regulatory documents related to buildings' energy performance which imply economic and management aspects, are:

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[1] [†] This paper represents a summary, partially updated and adapted to the SEB Conference topics, of the main contents of the book Fregonara E. Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali. Milano: Angeli; 2015. For further discussion, please see the cited publication.

- the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Off. J. Eur. Union (2010)
- the Guidelines accompanying Commission Delegated Regulation (EU) n. 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council, Off. J. Eur. Union (2012) on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements
- the standards ISO 14040:2006, Environmental Management – Life Cycle Assessment – Principles and Framework prepared by Technical Committee ISO/TC 207, Environmental Management, Subcommittee SC 5, Life Cycle Assessment
- the standards ISO 15686:2008, Buildings and constructed assets – Service-life planning, particularly Part 5: Life Cycle Costing, prepared by Technical Committee ISO/TC 59, Building construction, Subcommittee SC 14, Design life
- the ISO 21500:2012, Guidance on Project Management, prepared by Project Committee ISO/PC 236, Project Management

In Italy, standards ISO are transposed by the Italian National Institution for Unification (UNI). The Directives on buildings energy performance are transposed in specific laws, at national or regional or local level.

Some relevant aspects, under an economic point of view, emerge from the documents mentioned. These aspects will be briefly commented in the following sections.

3. Cost categories and approaches for energy-environmental-economic sustainability

Three relevant cost concepts emerge from the documents mentioned in section 2: Whole Life Cost (WLC), Global Cost (or Life Cycle Cost - LCC, or Total Life Cycle Cost), Cost Optimal.

The WLC is normed by the standard ISO 15686 – Part 5, for Life Cycle Costing. WLC represents the set of the relevant costs and benefits, with reference to the initial and future time period, during the whole life cycle and able to satisfy the performance requirements. It can include externalities, costs not directly connected to the construction, income (savings on operation expenses or "negative costs").

The LCC refers to an asset or to its components costs during the life cycle, reaching performance requirements. Both WLC and LCC consider the environmental cost component. Furthermore, WLC and LCC are related to the different life cycle phases in construction (see Fig.1). The Global Cost concept – the foundation for the Life Cycle Costing approach (see next Section) - is defined in the Standard EN 15459, Energy performance of buildings – Economic evaluation procedure for energy systems in buildings, Brussels, CEN, 2007, with the aim to harmonize the methodology for building energy performance calculation at European level. The Standard represents the methodological base for the Global Cost economic calculation, specifically for heating systems; it considers data from other systems that can influence the energy demand of the heating system. The calculation is founded on two approaches: the global cost method, and the annuity method [5]. The Global Cost can be used for: verifying economic feasibility of energy-saving options, comparing the energy consumption of alternative solutions, calculate the economic performance of a building as a whole etc. In order to apply the methodology it is necessary to know, among the others: financial input data (e.g. calculation period, inflation rate, real interest rate, market interest rate, energy costs inflation rate etc.), investment costs by consulting appropriate sources (e.g. price lists of a specific Region); periodic replacement costs (with considerations on the mean lifespan of components); annual maintenance costs (percentage on components cost); energy costs (e.g. heating, lighting, electricity etc.); residual value of an asset and/or residual values of each component.

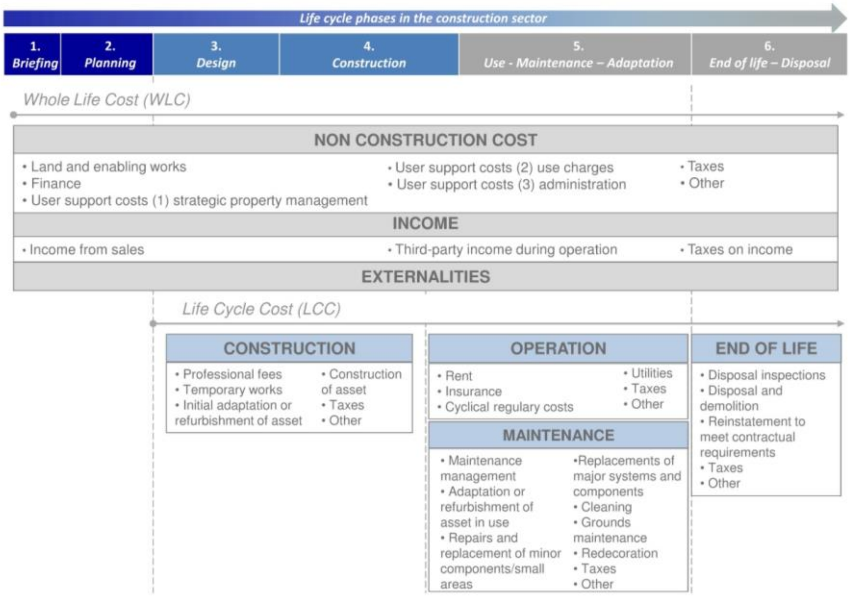

Fig. 1. WLC and LCC: relevant components and their distribution along life cycle phases in the construction sector (source: elaboration from ISO/FDIS15686 – Part 5:2008 (E), Fig. 3)

Cost Optimal is the base concept of a standardized methodology which aims to the calculation of the energy performance optimal level, in relation to costs [6,7,8]. Cost Optimal sets the minimum energy performance level required for buildings, considering the Energy Class. It is defined by the Directive 2010/31/EU (EPBD recast) and Guidelines, and by the following Commission Delegated Regulation (EU) n. 244/2012 (transposed in Italy in the document published in Gazzetta Ufficiale 2012/C 115). The EPBD recast provides each State Member, at national/regional level, develop a series of type buildings representatives of the building stock heritage, to be taken as reference and on which simulate energy efficiency scenarios. The energy simulations can be supported by software (e.g. Energy Plus – Energy Simulation Software, U.S. Department of Energy, http://apps1.eere.energy.gov/buildings/energyplus). The economic simulations can be provided through the Global Cost calculation method. The approach can be applied both in the case of new built constructions, and in the case of built heritage retrofitting [9].

It must be stressed that these cost categories can support the definition of project scenarios, which can be verified with a Discounted Cash Flow Analysis (DCFA), considering also investment profit and savings of each technological solution, as will be remarked in Section 5.

4. Life cycle concept and energy-environmental-economic sustainability

Life cycle is the base concept for Life Cycle Thinking (LCT) and Project Management (PM) approaches. Among the most important methodologies deriving from LCT is worth mentioning (the approaches deriving from PM will be discussed in Section 5):

- Life Cycle Assessment (LCA) defined by ISO 14040/44:2006 [10]. LCA is a method for evaluating and quantifying energy and environmental charges and potential impacts associated to a product, to a process or an activity, considering their life cycle. Service life is the key concept for the application of the method. Service life does not overlap with the building lifespan (normally longer) but with the lifespan taken into consideration for the analysis. LCA is very flexible: set a target, it adapts to the geographic context and to the case under consideration. LCA can be developed at the single component or technical element scale, or at the building scale, in function of the performance requirements and technological-architectural solutions

- Life Cycle Costing (LCC) or Life Cycle Cost Analysis (LCCA), defined by ISO 15686–5:2008. LCC, «a technique which enables the systematic appraisal of life cycle costs over a period of analysis», is an approach for quantifying costs and benefits with particular regard to costs along the whole life cycle, for supporting decisions among alternative design solutions/components/single materials, including efficiency and effective criteria. The LCC methodology, shared among European Member States, is formalized for example in the report produced by Davis Langdon in 2007 [11]. LCC represents a technique for project economic evaluation in the new/existing building construction sector, looking at immediate/long term costs and benefits (usually savings), through the calculation of quantitative indicators (Net Present Value, Net Present Cost, Net Savings, Discounted Pay Back Period etc.). For an LCC application it is necessary to know data on costs, cost profiles of each option considered (graphically expressed by an LCC Profile, see Fig. 2), and financial input data. It represents a decision making support tool, which can be applied to different cases: an individual product or component, an entire building component system (e.g. HVAC systems), a new building project, a retrofit of an existing building. LCC can be applied with different purposes: to compare technical alternative solutions, assessing the relative difference among life cycle costs; to define a ranking among alternative projects, focusing on the benefits obtainable by each investment unit, in the presence of limited resources; to assess the budget of a selected project in a fixed lifespan

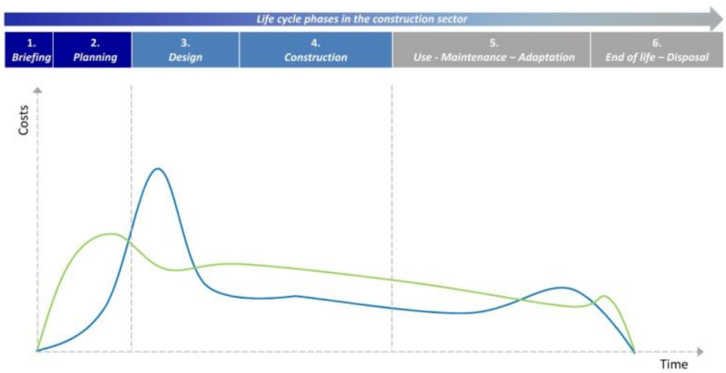

Fig. 2 – Cost profiles for LCC Analysis: LCC Profiles (LCCPs) (source: elaboration from Fregonara E. Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali. Milano: Angeli; 2015, Fig. 5, p. 111)

Other approaches deriving from life cycle concept have been developed usually for experimenting the integration of models. Among these, Life Cycle Sustainable Assessment (LCSA), stated in 2011 as a result of the studies within the United Nations Environment Programme – UNEP [12]. It considers the economic, environmental and social sustainability aspects separately, synthesizing the results in a final valuation. The approach combines Environmental LCA (for energy impacts analysis with particular attention to materials/technologies), Economic LCA (for economic impacts analysis, through for example LCC), Social LCA (for social impacts evaluation). Furthermore, Social Life Cycle Assessment (SLCA), for evaluating the social impact produced by a low consumption or passive new building or retrofitting intervention, compared to a traditional construction, on the basis of best practices of energy saving and efficiency implemented by users [13]. The approach aims to make retrofit or new building interventions better integrated into their social, economic and local context, specifically in the great works with relevant impacts in terms of social utility. In other studies, methodologies for evaluating economic-environmental efficiency at the building or single component scale are developed: for example the methodology developed by Society of Environmental Toxicology and Chemistry (SETAC) from 2003, based on LCC, LCA and Environmental LCC (ELCC) [14]. Recently, research is focusing on evaluation methods capable to simultaneously verify the project (or its parts) economic and environmental sustainability, through economic and environmental indicators. Focus is given to the quantification of the "global performance" of the project [15].

Some studies consider LCC and LCA conjoint approaches, to support decision making process. For example, the proposal developed in 2013 within the CILECCTA project based on conjoint LCC and LCA economic-environmental sustainability in the building sector [16].The synergetic use of LCC and LCA can be proved: in the presence of a single project option or a set of alternative options, including LCC and LCA results in the set of evaluation criteria; in economic-financial evaluation using LCC of a set of options previously selected or identified thorough LCA, focusing on alternatives with better environmental performances; in environmental evaluation with LCA application, focusing only on cost-effective options according to LCC results; in LCC applications for economic-financial evaluation of environmental impacts which are expressed – if possible - in monetary terms.

The following Fig. 3 summarizes the evaluation methods, during the life cycle phases.

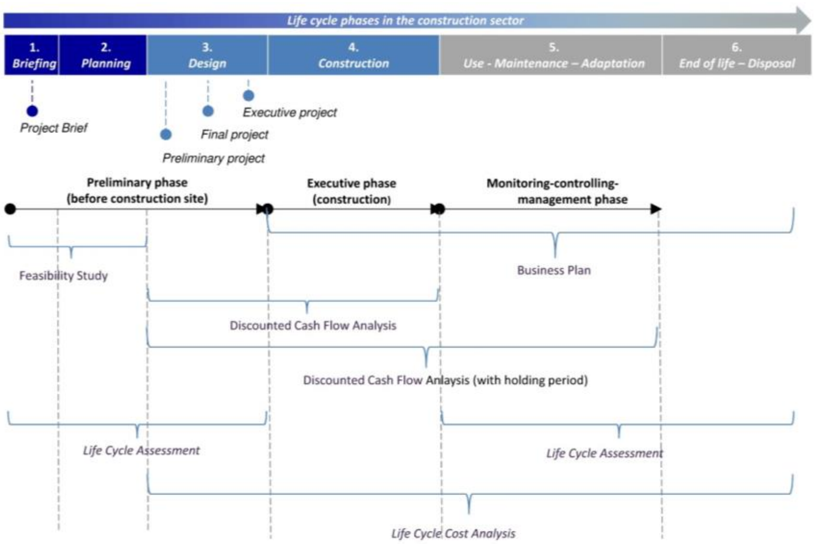

Fig. 3 – Project Economic Evaluation methods. Distribution along life cycle phases (source: elaboration from Fregonara E. Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali. Milano: Angeli; 2015, Fig. 9, p. 29)

Notice that in Fig. 3 some consolidated project evaluation techniques such as Feasibility Studies, Discounted Cash Flow Analysis, Business Plan, which are normally referred to the construction and management phases, are here considered respect to the whole life cycle. Furthermore, notice that LCC and LCA approaches overlap in some phases, confirming the opportunity to apply them conjointly.

5. Project Management approach and energy-environmental-economic sustainability

Currently, PM is applied in contexts with high degree of innovation, characterized by uncertainty and high technical-organizational complexity [17]. For example, in the context of architectural or civil engineering works, or project driven activities such as design and engineering companies. PM is consolidated in the industrial sector, and specifically in the building construction or management activities, but also in facilities and public administration sectors. Time, cost and quality are the basic principles. The two main PM standards are: A Guide to Project Management Body of Knowledge (PMBOK Guide), fifth edition published in 2013 by Project Management Institute (PMI). The guide, approved by American National Standards Institute (ANSI), is drafted with the aim to standardize PM common practices; the Standard ISO 21500:2012 (mentioned in Section 2), which is drafted with the aim to highlight the relevant concepts and processes, looking at the best practices in project management. The Standard ISO 21500:2012 identifies PM relevant processes which must be adapted to the specific strategies of companies, even in the building sector. It takes into account both the whole project and the parts of a project. Special attention is devoted to the processes interaction, and the subjects involved, with their requirements and aims. The document classifies PM processes in (see Fig. 4): Process Groups: Initiating, Planning, Implementing, Controlling, Closing; Subject Groups: Integration, Stakeholder, Scope, Resource, Time, Cost, Risk, Quality, Procurement, Communication.

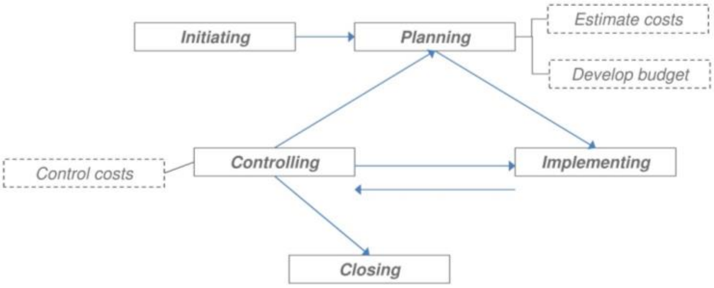

Fig. 4 – Interrelations between PM processes groups (source: elaboration from BS ISO 21500:2012, Guidance on PM, Fig. 5, p. 11)

Process Groups Planning are finalized to develop detailed planning activities in order to allow the management of the project implementation, the measurement and control of the project performances. These are concretized in Estimate costs activities (or Project Cost Estimating) and Develop budget activities (or Project Budgeting). Process Groups Controlling are finalized to project performances measuring and control respect to the planned performances, in order to define corrective actions and to reach the targets. These processes are concretized in Control Costs activities, based on monitoring.

5.1. Project Management and the life cycle phases in the construction sector

The Life cycle concept is a pillar for theories and practices of PM; it is conceived as a «defined set of phases from the start to end of the project». Respect to the project life cycle PM is articulated in two groups of activities, as shown in Fig.5: Project Construction Management; Asset, Property and Facility Management.

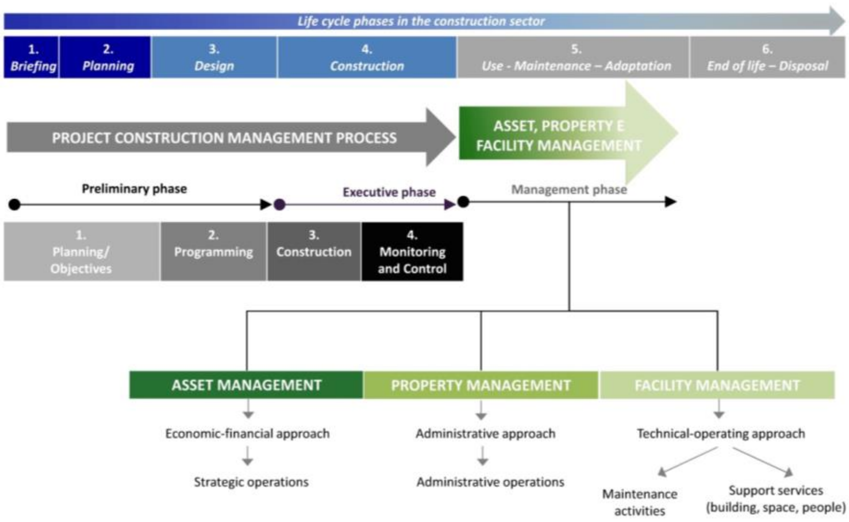

Fig. 5 – Life cycle phases and PM activities: Project Construction Management and Asset-Property-Facility Management (source: elaboration from Fregonara E. Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali. Milano: Angeli; 2015, Fig. 5, p. 177)

Specific tools support each PM phase. As concern Project Construction Management, central role is played by approaches to support: time and costs programming, and economic programming; management of the executive activities; monitoring and controlling. Executive and monitoring techniques are particularly important, specifically the Cost Control approach which founds on the calculation of project metrics and performance indexes. These metrics and indexes are the base for Earned Value Method application - at the time being the most advanced technique for measuring performance and progress in a project – according to a series of steps [18]: measurement of the project progress, deviations analysis, calculation of the project time to completion, and times and costs reprogramming. Besides, relevant methods - not only for economic programming as will be said in the following sub-section - are Budget, Discounted Cash Flow Analysis, Risk Analysis/Cost Risk Analysis.

These three groups of operative approaches are strictly correlated. Economic programming and monitoring-controlling techniques present theoretical and practical linkages, despite in literature they are treated separately. Together they lead to the definition of the Project Management Plan; this can be considered as the result of the project economic controlling process, which includes the identification of deviations causes, the execution of the corrective interventions and the check of their effect, even at a financial level.

5.2. Cost Control, Discounted Cash Flow Analysis, Cost-risk Analysis

In this last sub-section we present a proposal with the aim to support sustainability, through the treatment and possibly the reduction of the risk and uncertainty components of the project. Risk/uncertainty components are usually modelled in terms of market risk (or economic risk) and of technical-technological risk. The first one is linked to the marketing phases (selling, rent, holding etc.), the second one is linked to the executive project phases (construction activities, organization, security etc.). Both influence on profit, even if in a different manner. The first component is more difficult to control being correlated to an external system (the market), therefore to the complexity in predicting demand, supply, prices dynamics and liquidity. The second component is related to the internal system (the construction). It results more controllable, being linked to executive management, securing and controlling activities [19]. In the economic literature the market risk is more studied, given the correlations with investment analysis and with the real estate market. In the economic engineering literature, on the contrary, the cost concept is deeply treated, specifically through Cost Risk Analysis.

6. Discussion

In this section we try to triangulate the findings of the literature and regulatory context, the observations from the methodology and also the results. These last consist in the synthesis of the main groups of tools and approaches developed within the economic-evaluative discipline and able to support sustainability in energy and buildings, and, simultaneously, some considerations. Among the last it is worth mentioning: an increasing evidence that financial institutions are recognising the connection between energy performance and asset value; orienting the market towards high performance buildings implies impacts on design, on asset assessment practices, on evaluation of projects, with an increasingly central role of quality; the presence of environmental, economic and energy impacts, affecting the market (for example, in terms of demand shifting toward eco-compatible buildings, supply and industrial positioning toward quality building products).

All these considerations make the solution selection more critical and, as a result, emerges the necessity:

- to refine the classic evaluative theory and tools toward a technological-economic evaluation of project
- to extend the (consolidated) vision of the time horizon of the project from the construction phase to the entire life cycle, and, consequently, to distribute the project economic evaluation methods along the life cycle phases
- to verify the project or its parts with evaluation and management methodologies able to simultaneously measure environmental and economic sustainability, in terms of global performance, in relation to building (or building components) life cycle
- to deepen the knowledge and applicability of conjoint approaches for supporting economic sustainability (LCC) and energy-environmental sustainability (LCA), considering that these can lead to different results

Furthermore, considering specifically the Italian context, the most relevant challenge proposed in this work – which represents an element of originality according to which develop the future research on the topic – is the necessity:

- to explore the applicability of economic programming approaches, focusing on the conjoint use of cost monitoring and control approaches and financial analysis, according to an approach able to associate Cost Control, Discounted Cash Flow Analysis and Cost-risk Analysis
- to analyze market and cost risks, specifically in complex projects with different functions, extending the focus given to market risk by the traditional approaches toward cost-market risk

In fact, the state-of-the art reveals the opportunity to treat the two components – market risk and cost risk – jointly, connecting risk analysis, cash flow programming and cost monitoring and control, on the base of the following considerations:

- cost variation can perturb a financial result. These can be modelled for example through DCF Analysis. Market risk usually is quantified using adjusted discount rates; cost risk component can be modelled with cost risk indicators such as project metrics and performance indexes, graphically supported by S curves (defined, in the context of Cost Risk Analysis, as project Cost Cumulative Distribution Function) [20]
- reprogramming to finish can be developed respect to economic programming objectives (through DCF Analysis) and not only respect the budget, which is defined as a function of the market. Costs variations imply a re-modelling of financial plan
- Cost Control can be developed maintaining costs and time within a range of financial feasibility. Variations in costs can influence selling prices, variations in time can influence the project timing: both must be verified respect to market conditions, which can consent, or not, increasing in prices and/or longer deadlines through DCF Analysis it is possible to remodel costs and time and, through Risk Analysis resolved with Sensitivity Analysis (deterministic or probabilistic), it is possible to manage the technical-economic process. In this case, thresholds defined through market analysis can be assumed, with the aim to fix the acceptability of effective costs compared with budgeted costs (and similarly for times), and in the meanwhile with the aim to define the investment market conditions

The expectation is that this work could be the starting point for other researches, and that the relationships between the Real Estate Appraisal and Project Evaluation discipline and the Building Physics discipline would be increasingly studied in order to strengthen their synergy.

7. Conclusions

In the paper is presented a view of the main estimative-evaluative methodologies for supporting sustainability in energy and buildings. In the first part of the paper, the most recent international legislation in the context of the energy sustainability of buildings are mentioned; particular attention is posed on the concepts of cost and life cycle. Then, focus is given to the cost concepts (specifically the Whole Life Cost, Life Cycle Cost and Cost Optimal) and their calculation for energy-environmental-economic sustainability, starting from the Standards, regulations and methodological guidelines mentioned before. Through the examination of documents the issues which can be dealt with economic tools are identified. Subsequently, the approaches and tools selected are organized in a cohesive structure. On these basis, the central part of the paper is devoted to summarize the most relevant approaches emerging from the literature, distinguishing the following groups: methods deriving from the Life Cycle Thinking approach, specifically the LCC and LCA approaches; methods deriving from the Project Management approach, considered in relation to the life cycle phases; tools directed to the reduction of risk and uncertainty elements of the project, with particular attention to the potentiality of Cost Control and Cost Risk Analysis, in conjunction with Discounted Cash Flow Analysis, as a tool to support management activities and decision making processes. Finally, a brief discussion concludes the paper.

References

[1] Fregonara E, Curto R, Grosso M, Mellano P, Rolando D, Tulliani JM. Environmental Technology, Materials Science, Architectural Design, and Real Estate Market Evaluation: A Multidisciplinary Approach for Energy-Efficient Buildings. J Urban Technol 2013; 20:57-80.
[2] Thiebat F. Life-cycle design for sustainable architecture. Techne 2013; 05:177-183.
[3] Fregonara E, Rolando D, Semeraro P, Vella M. The impact of Energy Performance Certificate level on house listing prices. First evidence from Italian real estate. Aestimum 2014; 65:143-163.
[4] Fabbri K, Tronchin L, Tarabusi V. Energy retrofit and economic evaluation priorities applied at an Italian case Study. Energy Procedia 2014; 45:379–384.
[5] Ministère de l'ècologie, de l'énergie, du dèveloppement durable et de l'aménagement du territoire, Calcul du Coût Global. Objectifs, méthodologie et principes d'application selon la Norme ISO/DIS 15686-5; 2009.
[6] Becchio C, Ferrando D, Fregonara E, Milani N, Quercia C, Serra V. The cost optimal methodology for evaluating the energy retrofit of an ex-industrial building in Turin, 6th International Building Physics Conference, IBPC 2015, Turin, Italy, 14–17 June 2015. Energy Procedia 2015; 78:1039-1044.
[7] Becchio C, Fabrizio E, Dabbene P, Monetti V, Filippi M. Cost optimality assessment of a single family house: Building and technical systems solutions for the nZEB target. Energy Build 2015; 90:173-187.
[8] Corrado V, Ballarini I, Paduos S. Assessment of cost-optimal energy performance requirements for the Italian residential building stock. Energy Procedia 2014; 45:443–452.
[9] Ascione F, Cheche N, De Masi RF, Minichiello F, Vanoli GP. Design the refurbishment of historic buildings with the cost-optimal methodology: the case study of a XV century Italian building. Energy Build 2015; 99:162–176.
[10] König H, Kohler N, Kreissig J, Lützkendorf T. A life cycle approach to buildings. Principles, Calculations, Design tools. Regensburg: Detail Green Books; 2010.
[11] Langdon D. Life Cycle Costing (LCC) as a contribution to sustainable construction: a common methodology – Final methodology, 2007. Available online: http://ec.europa.eu/enterprise/sectors/construction/studies/life-cycle-costing_en.htm.
[12] United Nations Environment Programme UNEP Towards a Life Cycle Sustainability Assessment: Making informed choices on products, 2011.
[13] Muthu SS. Social Life Cycle Assessment, Environment Footprints and Eco-Design of Products an Processess, Springer; 2015
[14] Thiebat F. Life-cycle methods as design tools for sustainability assessment of technologies. In: What is sustainable technology? The role of life cycle-based methods in addressing the challenges of sustainability assessment of technologies. Proceedings of 2° DIRE Meeting. Rome 27 September 2012. Rome: ENEA; 2012. p. 72-74.
[15] The CILECCTA partners Sustainability within the Construction Sector. CILECCTA – Life Cycle Assessment. Oslo: SINTEF Academic Pres; 2013. Available online: http://www.cileccta.com.
[16] Hunkeler D, Lichtenvort K, Rebitzer G. Environmental Life Cycle Costing. New York: SETAC Books, CRC Press; 2008.
[17] Kerzner H. Project Management. Milano: Hoepli; 2005.
[18] Fleming Q, Koppelman J. Earned Value Project Management, Edition Number 4. Project Management Institute; 2010.
[19] Curto R, Fregonara E. Decision tools for investments in the real estate sector with risk and uncertainty elements. Jahrb Regionalwissensc 1999; 19:55-85.
[20] NASA Cost Estimating Handbook (CEH), Appendix G – Cost Risk and Uncertainty Metholodogies, Version 4.0; 2015. Available online: https://www.nasa.gov/offices/ooe/CAD/nasa-cost-estimating-handbook.