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Analysis of Energy Retrofit Assessment Methodologies in Buildings by European Research Projects

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***Abstract* – Energy retrofit of existing buildings is one of the main keys to achieve European Union's decarbonising objectives defined in the European Green Deal. In order to proceed into them, European policy has been adapted and several research projects are developed. The aim of this paper is to analyse the assessment methodology of the research projects, setting up the overview of the assessed fields and the criteria followed to perform and evaluate each project. As working methodology, 18 projects have been studied, firstly characterising by the main parameters and afterwards analysing the assessment followed by each one. This analysis is decomposed into five parameters: the assessment scope, reflecting the fields covered by the project's assessment; data source, the nature of the data; verification, use of data verification strategies; and implementation of life cycle thinking in the assessment methodology. The research shows that although the projects have their bases in the EU energetic targets they also cover a wider scope, assessing many fields and combining many sources of data. However, despite the large knowledge already defined by many projects, there is a lack of global and complete roadmap to be followed.**

***Keywords* – Building energy renovation; decarbonising; energy-efficient buildings; energy transition; holistic renovation; Life Cycle Assessment; urban regeneration**

1. INTRODUCTION

Buildings are responsible for about 40 % of the energy consumption and the 36 % of greenhouse gas emissions of the European Union (EU), taking into account all the stages of buildings' life; that makes them one of the biggest contributors to the greenhouse effect [1]. In response to this, improving energy efficiency is an important playground in order to achieve the European Green Deal by 2050, the goal of carbon-neutrality [1].

According to European Commission, around 75 % of the EU building stock is inefficient, and only 0.4 %–1.2 % of them are renovated per year [1]. Higher renovation rates could make significant reduction of energy consumption and greenhouse gas emissions, and here is one of the big deals, so in order to achieve the climate and energy objectives this rates should be at least doubled [1].

The EU has prepared and updated the legislative framework with the revision of the Energy Performance of Buildings Directive (EPBD) 2010/31/EU [2] and the Energy Efficiency

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Directive (EED) 2012/27/EU [3] in 2018 by the Directive 2018/844 [4], as part of 'Clean Energy for all Europeans' package [1]. The EPBD Directive was adopted in 2002 to promote the improvement of energy performance in buildings and in 2010 it was updated, with new aspects including the Recommendation List of Measures (RLM) for renovation of existing buildings [5].

The main objective of the Directives is to increase the energy performance in the scale of EU by 2030, and as linked objective, to use renewable sources at least in the 32 % of the energy [1]. Moreover, European Union has set ambitious commitments to reduce the greenhouse gas emissions by at least 40 % by 2030 comparing to 1990, to increase the use of renewable energy and to achieve energy in accordance with the EU level ambitions [6]. In order to follow this, in the 2a article of the EPBD it is established that member states must ensure a highly energy efficient and decarbonised national building stock by the use of Long-Term Renovation Strategies (LTRS), with milestones every 10 years, until 2050 [7]. In addition, the EPBD and EED Directives recommend to use measurable indicators to assess the process related to many aspects that can bring many benefits: clean energy transition, economic stimulation, contribution in comfort, health and wellbeing of the residents and reduction and control of energy poverty [1].

In order to achieve these targets and build roadmaps to lead the member countries, many research projects are being performed. They propose several solutions and provide new perspectives in terms of improving the existing building stock in Europe. Despite all of them follow the same main goals, they are developed in several working fields and under different assessment methods.

2. OBJECTIVES AND METHODOLOGY

The aim of this paper is to set up the overview of assessment methodologies followed in the performance and evaluation of building energy retrofit research projects linked to the European Green Deal. This analysis will reflect the criteria and the roadmap of the projects' assessment in terms of the covered field, data management and the extension of each project's evaluation procedure.

As working methodology, energy retrofit projects have been analysed, focusing on the assessment methodology followed. The chosen projects are research projects directly linked to the European Green Deal [1] and the Directives that rule the targets to achieve them in the field of existing buildings [4]. The analysed projects have been limited to 18, making it possible to have an extended view with diverse feature projects; alike, the chosen projects are performed in the period of 2012–2022 (some of them are not finished yet).

First of all, the projects have been characterised according to the main parameters, making it possible to describe each of them: type of project, scale, period, research program, coordination entity and the budget of each project (see Table 1). Three types of projects have been chosen, (methodology development, energy action plan and tool development) representing the picture of European energy retrofit research projects of the last years.

Afterwards, the assessment methodology used by each project is analysed according to four parameters: assessment scope, data source, verification and use of life cycle methods (see Table 2). The assessment scope defines the extension of the projects' evaluation methodology, classifying into different fields to assess: energy, environment, economy, social, wellness & health and heritage. The data source defines the origin of the data used to measure each assessment scope, classified into three types: Real Data (directly measured, monitored, by samples etc.), Estimated Data (by simulation, interpolation, data-bases etc.) and Perceptive Data (by surveys, interviews etc.). The verification checks the use of data verification strategies (Yes/No/no data) in each assessment scope of each project. Finally, the use of life cycle analysis checks the use of the life cycle thinking (Yes/No/no data) in the performance and evaluation of the projects the case of environmental, economic and social scopes (the three fields studied by the Life Cycle Assessment methodology).

3. RESULTS

3.1. Characterisation

Many types of renovation projects have been done, with different scale, aim and criteria, involving different disciplines and entities. In order to follow a normalized characterization, the projects have been classified according to main parameters: type, scale, period, program it belongs, entity is in charge of the coordination and budget (see Table 1).

The TYPE of the project defines the nature of the project, most of times determined by the outcome of the project, and can be classified into three different types: Methodology Development, Energy Action Plan and Tool Development. Most of the projects analysed are based in the Methodology Development, researching in the applicability of renovation strategies, but focusing in different working areas and purposes. The project ENERPAT [8], [9] and EFFESUS [9] are based on eco-renovation solutions of the housing of historic centres, experimenting on networks of cooperation. ALDREN is based in the utility of the Building Renovation Passport (BRP) [10], [11]. With a different working field, the REFURB [12][13] project proposes different renovation packages based not only on energy, also on features and needs of the dwelling and dwellers, creating a methodology. Furthermore, BIM (Building Information Modelling) based methodologies are also developed, like RenoZEB project [14], researching in new renovation constructive solutions using prefabricated elements. Another type of project is the development of an Energetic Action Plan for cities, the projects REPICATE [18], [19], GrowSmarter [20], ReemoUrban [35], and STEEP [22], [23]; they follow a similar schedule with three main working areas one of them being the improvement of energy efficiency of existing buildings. Tool development research projects also have been analysed, focusing on different working areas and systems, but all of them based on the use of a software to attend energy retrofit renovation projects, like OptEEmAL [24], [25], based on different energy conservation measures in to perform the energy use at building and district scale; EASEE [26], [27] focused on innovative envelope solutions; Paradis [28], [29], which generates and assesses optimal renovation scenarios; and ENERSI [30], a multi-disciplinary data management tool.

The SCALE defines the influence area of the research, most of times according to the institutions involved in the project. Three main scales have been determined: European, National and Territorial. European projects are more directly linked to the targets of the European Directive previously mentioned, and most of them are based in the cooperation between different entities from different countries, and in this study all these projects are funded (entirely or part of it) by the European Union. National projects are not common, and there are only two national projects analysed here, both of them tool developments; the main feature of these projects is that they are focused on the building typology of the country. Finally, the territorial projects could be the final part of the chain of renovation projects, acquiring knowledge from bigger scale projects and applying in more specific scenarios.

The PERIOD defines the time when the project was carried out, what is more important, the time covered (all of them are linked to the European directives targets, so the time location is not relevant). It has been seen that almost all the projects lasted for 3–4 years, even with different type, scale and budget.

TABLE 1. RENOVATION PROJECTS REVIEW

Project name	Type	Scale	Period	Program	Coordination entity	Budget
ENERPAT [8], [9]	Methodology development	Europe	2016–2019	Interreg SUDOE	SUDOE	1.89 M€
EFFESUS [9]	Methodology development	Europe	2012–2016	Seventh EU Framework	Tecnalia, Fraunhofer-Intitute	6.79 M€
ALDREN [10], [11]	Methodology development	Europe	2017–2020	*Horizon 2020*	Centre Scientifique et Technicque du Batiment	1.98 M€
REFURB [12], [13]	Methodology development	Europe	2015–2018	Horizon 2020	Flemish Institute for Technological Research	2.07 M€
RenoZEB [14]	Methodology development	Europe	2017–2021	Horizon 2020	Solintel M&P SL	8.71 M€
REVALUE [15]	Methodology development	Europe	2015–2019	Horizon 2020	Bax Innovation Consulting	1.57 M€
mPOWER [16], [17]	Methodology development	Europe	2018–2022	Horizon 2020	Univeristy of Glasgow	2.00 M€
REPLICATE [18], [19]	Action Plan	Europe	2016–2021	Horizon 2020	Municipality of Donostia	29.30 M€
GrowSmarter [20]	Action Plan	Europe	2015–2019	Horizon 2020	Stockholms Stad	35.80 M€
RemoUrban [21]	Action Plan	Europe	2015–2020	Horizon 2020	Fundación Cartif	24.75 M€
STEEP [22], [23]	Action Plan	Europe	2016–2020	Seventh EU Framework	Municipality of Donostia	2.63 M€
OptEEmAL [24], [25]	Tool development	Europe	2015–2019	Horizon 2020	Cartif Technology Centre	4.24 M€
EASEE [26], [27]	Tool development	Europe	2012–2016	Seventh EU Framework	Rina Consulting SPA	7.68 M€
Paradis [28], [29]	Tool development	National	2016–2019	Revalue Research Program	Aarhus University	n/d
ENERSI [30]	Tool development	National	2013–2017	Spanish Nat. Research Plan	ARC Engineering and Architecture La Salle	n/d
Plan Zero CO_2 [31]	Action Plan	Territorial	2018–2021	Horizon 2020	Alokabide	n/d
AGREE [32], [33]	Methodology development	Territorial	2020–2022	Horizon 2020	Basque Government	0.56 M€
HEREVEA [34]	Tool development	Territorial	2015	Feder Andalucía	University of Seville	n/d

The PROGRAM and the COORDINATION define the belonging research program and the main funder, and defines the entity in charge of the management. All the European scale projects and most of territorial projects belong to the main research European programs: 'Interreg SUDOE' (abbreviation of Cooperation Programme Interreg V-B Southwest Europe), 'Interreg Europe', 'Seventh Framework Programme for Research and development' and 'Horizon 2020 Research and Innovation Programme'. The difference is made by the national scale projects, belonging to national research programs. However, the coordination is always carried out by national or territorial entities, even in European scale, but based in the coordination of many entities.

3.2. Assessment Methodology

As mentioned before, all the projects are linked to the targets of the European Green Deal [1], following the same main objectives but using different assessment and evaluation methodologies. In this section the assessment methodology followed by each project is analysed according to four parameters (see Table 2 and Annex for more details).

- **Assessment Scope:** Energetic scope, Environmental scope, Economic scope, Social scope, scope related to Wellness & Health, and scope related to Heritage.
- **Data Source:** Real (by direct measurement, monitoring), Estimated (by calculation, simulation, interpolation or from data-bases), and Perceptive (by surveys, interviews)
- **Verification:** Yes, No, n/d (no data); Use of data and result verification strategy.
- **LCA:** Yes, No, n/d (no data); Use of life cycle thinking assessment or methodology in the case of Environmental scope, Economic scope and Social scope.

TABLE 2. PROJECTS ASSESSMENT METHODOLOGY

Project	Assessment Scope	Data Source	Verification	LCA
ENERPAT	Energy	Real + Estimated	Yes	–
[8], [9]	Environment	Estimated	No	Yes
	Economy	Estimated	No	Yes
	Social	Perceptive + Estimated	No	n/d
	Wellness & Health	Real + Estimated	Yes	–
	Heritage	Real	–	–
EFFESUS	Energy	Estimated	No	–
[9]	Environment	Estimated	No	Yes
	Economy	Estimated	No	Yes
	Wellness & Health	Estimated	No	–
	Heritage	Real	–	–
ALDREN	Energy	Real + Estimated	Yes	–
[10], [11]	Economy	Estimated	No	Yes
	Wellness & Health	Real + Estimated	Yes	No
REFURB	Energy	Estimated	No	–
[12], [13]	Economy	Estimated	No	No
	Social	Estimated	No	No
	Wellness & Health	Estimated	No	–
RenoZEB	Energy	Real + Estimated	Yes	–
[14]	Environment	Estimated	No	n/d
	Economy	Estimated	No	No
	Wellness & Health	Real + Estimated	Yes	–
REVALUE	Energy	Estimated	No	No
[15]	Economy	Estimated	No	Yes
	Wellness & Health	Estimated	No	–
mPOWER	Energy	Estimated	No	–
[16], [17]	Environment	Estimated	No	No
	Economy	Estimated	No	No

Project	Assessment Scope	Data Source	Verification	LCA
	Social	Estimated	No	No
REPLICATE [18], [19]	Energy	Real + Estimated	Yes	–
	Environment	Estimated	No	No
	Economy	Real + Estimated	Yes	No
	Social	Perceptive + Estimated	Yes	No
GrowSmarter [20]	Energy	Real + Estimated	Yes	–
	Environment	Estimated	No	No
	Economy	Estimated	No	No
	Wellness & Health	Real + Estimated	Yes	–
RemoUrban [21]	Energy	Real + Estimated	Yes	–
	Environment	Estimated	No	No
	Economy	Estimated	No	No
	Social	Perceptive + Estimated	No	No
	Wellness & Health	Real + Perc. + Estim.	Yes	–
STEEP [22], [23]	Energy	Real + Estimated	Yes	–
	Environment	Estimated	No	Yes
	Economy	Estimated	No	No
	Social	Estimated	No	No
	Wellness & Health	Real + Estimated	Yes	–
OptEEmAL [24], [25]	Energy	Real + Estimated	No	–
	Environment	Estimated	No	No
	Economy	Estimated	No	Yes
	Social	Estimated	No	No
	Wellness & Health	Estimated	No	–
EASEE [26], [27]	Energy	Real + Estimated	Yes	–
	Environment	Estimated	No	No
	Economy	Estimated	No	Yes
	Wellness & Health	Real + Estimated	Yes	–
Paradis [28], [29]	Energy	Estimated	No	–
	Economy	Estimated	No	No
	Wellness & Health	Estimated	No	–
ENERSI [30]	Energy	Estimated	No	No
	Economy	Estimated	No	No
Plan Zero CO_2 [31]	Energy	Real + Estimated	Yes	–
	Economy	Estimated	No	No
	Social	Real + Perc. + Estim	No	No
	Wellness & Health	Real + Perc. + Estim	Yes	–
	Accessibility	Real	–	–
AGREE [32], [33]	Energy	Estimated	No	–
	Economy	Estimated	No	No
	Social	Estimated	No	No
	Accessibility	Real	–	–
HEREVEA [34]	Energy	Real + Estimated	No	–
	Environment	Estimated	No	Yes
	Economy	Estimated	No	No

Note: Indicators and topics performed in the assessment methodology of each project are indicated in the Annex.

3.2.1. Assessment Scope

Despite all the projects are linked to the EU energetic and environmental targets [1], each one follows a different criteria in their development, assessment and decision making, covering different fields named as 'Assessment Scope'. The 'Assessment Scope' indicates the evaluation fields performed by each project in their development and evaluation, by specific indicators in order to assess the specific fields defined in this paper (energy, environment, economic, social, wellness & health and heritage). This indicators and topics assessed by each project are indicated in the Annex.

In Fig. 1 the percentage of the projects assessing each 'Assessment Scope' is shown. Whereas, as mentioned before, European policies recommend the assessment of many aspects, such as clean energy transition, economic stimulation, contribution in comfort, health and wellbeing of the residents and reduction and control of energy poverty [1], not all of them are taken into account. This can also reflect the feasibility and easiness to assess each field. The Energetic Scope is mostly assessed together with the economic field, because the Energetic Scope is the base for all the projects, and the Economical Scope, because the economic factor is always one main condition to make the operation feasible. The next mostly assessed field is the Wellness & health scope, which shows the importance of this factor and is also one of the main targets of the European Directives [1], which creates a good opportunity for assessment methodologies. The Environmental Scope clearly shows the weakness of the present day energy retrofit assessment methodologies, as well as it covers the main final targets of the European Green Deal [1] included in 11 of 18 projects. So does the Social scope, being one of the targets recommended in the Directives and performed in half of the studied projects (9 of 18). Finally, the Accessibility and Heritage scopes play a minor role, becoming secondary targets being followed by these projects.

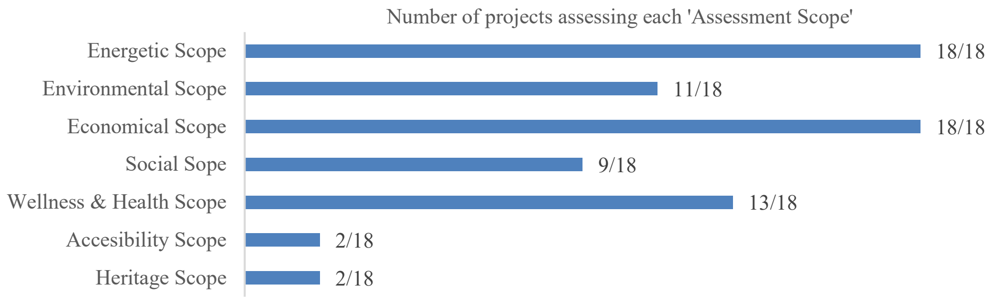

Fig. 1. Percentage of projects assessing each 'Assessment Scope'.

As all the projects are directed to the improvement of energy efficiency of existing buildings, the Energetic scope is the main assessed field and the core of all the projects, but each one is based on different techniques using several disciplines. Indicators used in the Energy Performance Certificates (EPC), introduced for the first time in 2002 by the EPBD (Directive 2002/91/EC) [36] and updated in 2018 by the Directive 2018/844 [4], are used in all the projects, like primary energy consumption and energy demand among others [37]. Furthermore, covering a wider evaluation, the embodied energy, energy related to the material and intervention energetic costs [38], is also taken into account in ENERPAT [9], EFFESUS [9], OptEEmAL [25] and HEREVEA [34].

Whereas all these projects are linked to environmental objectives, not all of them have a specific assessment in Environmental Scope, performing it in 11 of 18 projects. Most of the projects specifically assessed in the environmental field use the indicator of Greenhouse Gas (GHG) emissions or equivalent CO_2 emissions, linked to the main target of the EU of decarbonising the existing building stock [1]. One of the most complete evaluations performed are the ones based the Life Cycle Assessment (LCA) thinking, used in ENERPAT [9], EFFESUS [9] and STEEP [23]; this method evaluates the impact of each project with an overall view [39], explained in section 3.2.4. As a similar approach, HEREVEA [34] uses the Ecological Footprint (EF) method [40], that 'assesses the amount of land that would be required to provide the resources (grain, feed, firewood, fish, and urban land) and absorb the emissions (CO_2) of humanity' [34]; in this projects the standard UNE-EN15978 [41] was used to assess the project in the environmental impact.

The Economical scope has a specific evaluation in all the projects, but by different indicators and calculation methods. As a complete economic assessment, ALDREN [10], REVALUE [15], OptEEmAL [25] and EASEE [26] have used life cycle thinking methods, the Life Cycle Cost method (LCC) [42], for their economic calculations. With a similar treatment, ENERPAT and *EFFESUS* use the Circular Economy (CE) [9] bases, in this case also evaluating the whole life cycle in terms of economy [9]; further, they are focused on the local economy, enhancing the use of local material and techniques to boost local business and logistic easiness [9]. REPLICATE [19] and STEEP [23] have also analysed the opportunity to widen the local economy and benefit local businesses. Otherwise, as a detailed economic study, AGREE is focused on the financial support and viability to attend stakeholders in the economic evaluation of energy retrofit projects, concentrated in the territorial framework [33].

The Social scope englobes many indicators recommended by the European Directives [1]. However, in the analysed projects it takes a minor place as it is assessed in half of the projects (10 of 18). In these projects, the most evaluated aspect is the 'energy poverty' or the 'fuel poverty'; Foster *et al*. defined fuel poverty as 'its energy consumption does not meet basic energy needs' [43]; furthermore, Perez-Bezos *et al.* proposed an energy vulnerability assessment method for prioritizing the retrofitting of residential buildings [44]. In this research seven projects assessed the energy poverty: ENERPAT [9], REPLICATE [19], RemoUrban [21], STEEP [23], OptEEmAL [25], Plan Zero CO_2 [31] and AGREE [33]. OptEEmAL [25] project defined inhabitants suffering 'energy poverty' when 10 % of their incomes are used to pay energy bills [45]. As a more general aspect, in addition to energy poverty, more aspects about the 'social vulnerability' are also assessed by REPLICATE [19], Plan Zero CO_2 [31] and AGREE [33].

Wellness & health parameters describe comfortable and healthy indoor conditions, and it's necessary to understand them together with thermal performance of the building in order to reach good conditions of wellness & health and reduce the energy demand [46]. Nevertheless, it is not assessed in all the projects, only in 13 of 18 projects. Indoor thermal conditions are assessed all these 13 projects (ENERPAT [9], EFFESUS [9], ALDREN [10], REFURB [13], RenoZEB [14], REVALUE [15], GrowSmarter[20], RemoUrban [21], STEEP [23], OptEEmAL [25], EASEE [26], Paradis [28] and Plan Zero CO_2 [31]). In the case of GrowSmarter [20] standardized evaluation is applied by ISO-7730 [47] and ISO-7726 [48] International Standards. Covering a wider field, Paradis [28] and Plan Zero CO_2 [31] apply the Standard EN-15251 [49].

Accessibility issues are also an important field to assess as it is defined in one of the three diagnosis topics in the study of performance indicators to prioritise multi-family housing renovations of Monzón and López-Mesa [50]. In the research, 2 of 18 projects have a specific assessment for accessibility, both of them in territorial scale: AGREE evaluates the accessibility degree in the building and also inside the dwelling [33]; besides, the Plan Zero CO_2 performs it in four parameters: the accessibility to the entrance on the building, vertical accessibility, sensorial accessibility (identification, orientation and communication) and analysis of adapted housing [31].

Heritage preservation is also a field to perform in energy retrofit projects, as built heritage has architectural and cultural value, and also mirrors the people, the territory, the productive activity, and the culture that created it [51]. In the analysed projects 2 of 18 count with a specific assessment of heritage preservation, EFFESUS and ENERPAT , projects based on the renovation of the housing heritage of the historic centres [9].

3.2.2. Data Source

For the assessment it is necessary to quantify and qualify different parameters and indicators by using data. In this paper data sources have been classified into three types: real, estimated and perceptive. As it can be seen in Table 2, most of the assessment is made by estimated data, thus, data obtained by calculation, simulation, interpolation or by using databases or indirect measurements.

In the case of the energetic scope assessment, all the analysed projects use estimated data. Some of them, REFURB [13] and REVALUE [15] are based on the EPC, so they only make use of estimated data sources, as EPC-s are based in estimation of energy demand [52]. However, certain projects also evaluate their project by using real data sources, obtained by direct measuring, monitoring or by samples. In RenoZEB, façade integrated sensors are used to monitoring data in real time, including the measurement of solar radiation [14].

Environmental and Economic scopes indicators are not easy to measure to get real data; for instance, in the RemoUrban uses Digest of UK Energy Statics to calculate savings in carbon emissions [21]. In the economic field only REPLICATE use real data, measuring incomes and costs related to the intervention [18].

In the Social and Wellness & Health aspects perceptive data is also used, by non-technical indicators obtained by surveys or interviews; it can be a determinant data source as in the study of Jimenez-Bescos and Oregi, were they used a questionnaire to reinforce the energy computation estimation [53]. In ENERPAT, participation of stakeholders and citizens was an important pillar against the energy poverty and following the citizen acceptance [9] working on the social field. Besides in RemoUrban made surveys and interviews to occupants collecting data about satisfaction, comfort and problems [21], in this case also performing both social and wellbeing & health assessment scopes. In addition, Plan Zero CO_2 counts with occupants' participation strategies, working also in both social and wellbeing & health fields [31], and also REPLICATE do so assessing the social scope [18].

3.2.3. Verification

The accuracy of the results obtained by using assessment methodologies can be determined by the verification of data. Half of the collected projects (9/18) include a framework to carry out the verification of data and the efficiency of the retrofit intervention.

On the one hand, as the most significant point, the Wellness & Health assessment scope has a verification framework in most of the projects assessing this scope, 8 of 13 (ENERPAT, ALDREN, RenoZEB, GrowSmarter, RemoUrban, STEEP, EASEE and Plan Zero CO_2); so the feasibility to check the accuracy in this field is demonstrated, making this point a requirement for energy retrofit assessment methodologies. In the same point the lack of a verification procedure in this field can be considered a weakness in the assessment methodology.

On the other hand, REPLICATE counts with verification in the energetic, economic and social fields, such as job creation and unemployment rate as social indicators and verification of incomes and costs as economic indicators [18], [19], but as it is performed in 1 of 18 projects reflects the difficulty to carry on the verification in these fields.

3.2.4. Life Cycle Assessment

Finally, the application of Life Cycle Assessment (LCA) thinking methods are taken into consideration, a methodology that brings the opportunity to make a complete assessment of the impact caused by the project in the performed scope, taking into consideration the environmental, social and economic fields; that's why more and more studies are using it in the building sector, prioritizing this methodology among others [54]. Among the analysed projects four of them used a life cycle thinking in their environmental assessment scope, and another four in their economic scope.

As the most complete life cycle environmental assessment, ENERPAT carries out a complete LCA, by a specific study on the whole system [9]. Besides, in EFFESUS, life cycle was only focused in the characterization of the solutions and material, in the environmental field [9]; and in the case of STEEP also assess the impact taking into account the entire life cycle but in limited parameters [55]. Furthermore, HEREVEA counts with the evaluation of the projects' impact in all the stages of the life cycle but using the previously mentioned Ecological Footprint (EF) [40] method, that despite it's not the same as LCA, it has the perspective of assessing the complete impact of the an intervention in all its life stages [34].

In the economic field the most used method is the Life Cycle Cost (LCC) method, and was applied by ALDREN [10], REVALUE [15], OptEEmAL [25] and EASEE [26].

4. CONCLUSION

The paper presents the analysis of energy retrofit research projects in buildings linked to the EU energetic targets, based on the improvement of the energetic performance, in order to build an overview of the working fields treated and the criteria followed to perform and evaluate each project.

Despite all the projects are linked to the same energetic aims, all of them cover wider scopes, but with a different roadmap and measurement techniques. On the one hand, there are projects of many types and scale, so they have different aims in addition to the energetic field. However, even in projects with similar typology and scale do not have a common roadmap in the assessment: in the case of the European scale energetic action plans (REPLICATE [19], GrowSmarter [20], RemoUrban [21] and STEEP [23]), follow the same scheme in the planning scope, but they do not follow the same roadmap in the assessment methodology, performing and evaluating each project under different scopes, indicators and data sources. Moreover, in the case of tool developments, although they have several applications, the common assessment scopes use completely different criteria. On the other, in terms of the energetic assessment, even though all the projects have certain indicators in common, the key assessing elements and data sources have different origins.

In terms of environmental assessment, life cycle thinking is only implemented in four of the eighteen analysed projects, ergo, only these four projects try to evaluate the whole environmental impact, were the final main objectives of Directives are fundamentally the environmental impact taking into account all the stages of the buildings' life [1].

In conclusion, it does exist a big knowledge of energy retrofit renovation projects by methodologies, tools and action plans, but there is a lack of a global roadmap to be followed in order perform and assess the retrofit of existing buildings.

The continuation on this research, by the Project LOCAL-REGEN will be focused to fulfil these lacks, towards a global roadmap to be followed and proceed in the main objective of the 'European Green Deal'.

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ANNEX

INDICATORS AND DATA ASSESSED BY PROJECTS' ASSESSMENT METHODOLOGIES

INDICATORS AND DATA ASSESSED BY PROJECTS

Project	Assessment Scopes and assessed indicators and topics		
ENERPAT [8], [9]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– ECM (Energy conservation measures) – Embodied energy – Monitoring of energy performance	– Life Cycle Analysis application – Use of local materials – Environment conditions	– Application of circular economy – Local material and techniques to boost new local business – Economic return
	Social Scope	**Wellness & Health Scope**	**Heritage**
	– Energy poverty – Citizen acceptance	– Indoor environmental conditions	– Different solution filtered according to heritage impact
EFFESUS [9]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– ECM (Energy conservation measures) – Embodied energy	– Life Cycle thinking in use of materials – Use of local materials	– Application of circular economy – Local material and techniques to boost new local business and logistic easiness – Economic return
	Wellness & Health Scope	**Heritage**	
	– Indoor environmental conditions	– Different solution filtered according to heritage impact	
ALDREN [10], [11]	**Energetic Scope**	**Economical Scope**	**Wellness & Health Scope**
	– Non–renewable energy use – Energy performance by hourly energy simulation	– Global cost: energy, maintenance, replacement, Ghg, revenues – Economical risk – Economical value: rental value, rental growth, discount rate	– TAIL system assessing the Thermal environment; Acoustic environment; IAQ (indoor air quality); Luminous environment
REFURB [12], [13]	**Energetic Scope**	**Economical Scope**	**Social Scope**
	– EPC indicators – Energy saving by %	– Annual investment cost – Cost efficiency indicator	– User typology and solutions according to the user (dweller)

	Wellness & Health Scope		
	– Basic assessment of comfort by checking which renovation package gives a plus in comfort		
RenoZEB [14]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Energy savings – Equipment performance – Monitoring in real time: solar radiation, light, heat transfer)	– GHG emission savings	– Financial conditions analysed – Market opportunities and barriers analysed
	Wellness & Health Scope		
	– Thermal Comfort	– IAQ	– Illuminance
REVALUE [15]	**Energetic Scope**	**Economical Scope**	**Wellness & Health Scope**
	– EPC indicators – Energy performance index	– Life Cycle Cost – Incomes (rental housing), cost and market approach	– Thermal comfort – IAQ – Risk of mould – Sound protection
mPOWER [16], [17]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– RES (renewable energy source) % installed – HDD (heating degree days) & CDD (cooling degree days) – HEF (hidden energy flows)	– Total primary energy footprint – GHG emissions	– GDP (gross domestic product)
	Social Scope		
	– HDI (human development index)		
REPLICATE [18], [19]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Annual final energy consumption – RES % energy consumption	– CO_2 emissions – PM10 concentration – Noise pollution – Wastes and recycling rate – Water consumption	– GDP – Median dispensable income
	Social Scope		
	– Population dependence ratio – High education degree ratio – Affordability of housing – Fuel poverty	– Public participation – Unemployment rate – Jobs created – Degree of satisfaction	
GrowSmarter [20]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Reduction of energy use – Energy demand (kwh/m2), heating, DHW, lighting, HVAC) – Measurement standard (IPMVM)	– Reduction of CO_2 emissions	– Affordability indicators: Financial net present value (ENPV), Economic Rate of Return (ERR), Benefit/cost ratio (B/C ratio) – Assessment for economic sustainability

	Wellness & Health Scope		
	– Thermal indoor environment (ISO 7730, ISO 7726)		
RemoUrban [21]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Energy savings – Measurement standard (IPMVM)	– Saving in CO_2 – Reduction of environmental footprint	– Capital value of houses
	Social Scope	**Wellness & Health Scope**	
	– Surveys to occupants – Reduction of fuel poverty	– RH (relative humidity) and temperature – Percentage of Hours Properties Met Thermal Comfort Targets. – Occupants perception by post–retrofit surveys: comfort, physical health and emotional wellbeing – Air quality – Natural light	
STEEP [22], [23]	**Energetic Scope**	**Environmental Scope**	
	– Primary Energy Consumption: the whole life cycle. – Reduction of energy consumption – Increase of RES energy	– Concentration of contaminants – Waste and Recourses; Air quality: Water; Biodiversity and ecosystems; Noise; Landscape and Townscape; Soil and Land; GHG emission reduction; embedded carbon in extraction; manufacturing and transport; predicted lifetime emissions, emissions of deconstruction and re–use; opportunities for carbon sequestration	
	Economical Scope	**Social Scope**	**Wellness & Health Scope**
	– Return of capital – Opportunity to wider local economy and benefit for local businesses	– Political and institutional support analysed – Equality – Community cohesion	– Increase of residents' health and comfort
OptEEmAL [24], [25]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Primary energy consumption – Embodied energy	– Global warming potential GWP – GWP investment – GWP reduction	– LCC, life cycle cots – Operational energy cost – Investments – Return of investment – Payback period
	Social Scope	**Wellness & Health Scope**	
	– Energy poverty measured as % on inhabitants that use more than 10 % of their incomes to pay energy bills	– Local thermal comfort – Percentage Outside Range – IAQ – Visual Comfort	
EASEE [26], [27]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Energy consumption	– Reduction of CO_2 – Reduction of waste	– Economic impacts: cost effectiveness during the life cycle.
	Wellness & Health Scope		
	– Comfort levels		
Paradis [28], [29]	**Energetic Scope**	**Economical Scope**	**Wellness & Health Scope**
	– Energy consumption (reduction) – Energy frames defined in BR18	– Investment cost analysis	– Indoor thermal comfort and IAQ (EN 15251) – Discomfort hours – Degree of Satisfaction

			– Health and Wellbeing (indoor thermal comfort, IAQ and their effects on diseases)
ENERSI [30]	**Energetic Scope**	**Economical Scope**	
	– EPC indicators	– Cost & Return on investment analysis	
Plan Zero CO_2 [31]	**Energetic Scope**	**Economical Scope**	**Social Scope**
	– Following the targets of 2010/31/UE – EPC indicators – Heating system – Energy consumption – No Renew Prim Energy consumption – Air tightness (N50)	– Optimum cost methodology. Using simulation calibrated with real data	– Vulnerability and Energy poverty – Incomes of occupants. – Occupants profile (family type, age, conflicts)
	Wellness & Health Scope	**Accessibility Scope**	
	– Indoor hygrothermal comfort, PMV & PPD (EN–15251). – Indoor air quality	– Accessibility to the entrance – Vertical accessibility (lift) – Sensorial accessibility (identification, orientation) – Adapted housing	
AGREE [32], [33]	**Energetic Scope**	**Economical Scope**	**Social Scope**
	– Energy efficiency	– Big study about financial support and viability	– Social vulnerability (economic situation, house typology…) – Census tract size
	Accessibility Scope		
	– Accessibility analysis in the dwelling and the building		
HEREVEA [34]	**Energetic Scope**	**Environmental Scope**	**Economical Scope**
	– Energy from bills – Embodied energy	– EF–Ecological footprint (instead of LCA) in all the life cycle – EN-15978 standard, Sustainability of construction work	– Economical data from bills – Economical cost of the project, per m^2

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