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Knowledge Integration for Low Carbon Transition: The Case of Energy Retrofit

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ABSTRACT

The Energy Retrofit concept plays an important role in the transition to low carbon cities, because buildings make a transdisciplinary perspective. Thus, an integrated approach to research, learning and teaching in the built environment disciplines is required. The Authors present the final stage of the first work package of an H2020-Marie-Sklodowska Curie project, which focuses on the development of an Innovative Learning Platform for Knowledge Integration in Energy Retrofit. This paper, which first summarizes the conceptual framework that was elaborated in an earlier phase, focuses on the methodological approach that was used to define the relevant information networks concerning Energy Retrofit using a cognitive mapping technique. The methodology is applied to 10 case studies in order to explore the relationships between Energy Retrofit and built environment transformation processes. The methodological approach is structured as follows: 1) Collecting case studies; 2) Identifying main topics; 3) Coding list of concepts; 4) Defining relationships; and 5) Updating the conceptual framework. The findings show that the adopted methodological approach is useful for integrating diverse disciplinary perspectives and for improving users' cognitive skills that are involved in mutual and joint learning processes. In conclusion, this study presents an innovative approach to research, learning and teaching in built environment disciplines.

Keywords: Energy Retrofit; Built Environment; Integrated Project; Knowledge Integration; Design Education

1. Introduction

The Energy Retrofit (ER) concept plays an important role in the transition to low carbon cities, because the large amounts of existing buildings, which were built before the onset of the thermal regulations (i.e. built before 1970) (BPIE, 2011). Recently, new plurality disciplinary perspectives have required a deep revisiting of the traditional concept of ER, which was exclusively linked with the scale and technical aspects of the components of the building itself (i.e. building energy performance) (Ma, Cooper, Daly, & Ledo, 2012).

In the last three decades, sustainability scholars have recognized that the integration of plurality disciplinary perspectives is a fundamental component to better understand complex relationships of sustainable development (Dedeurwaerdere, 2013). Since the 1970s such relationships have been focused on the implications between ecological dynamics and all other dimensions of anthropic activities, which characterize the transformation of built environments (Viegas et al., 2016). Today, these implications play a vital role in addressing a large amount of issues about the sustainability of the built environment, involving both social and physical sciences.

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Several studies have explored the meaning of the ER concept emphasizing the connections among social and physical disciplines. For example, Gianfrate, Piccardo, Longo, & Giachetta, (2017) have focused on the relationship between technological advancements and knowledge in energy retrofitting with social needs and habits. Gregório & Seixas, (2017) have explored the holistic approach on a neighbourhood scale, instead of the traditional individual building scale. Glackin & Dionisio, (2016) have tested a new methodology for community engagement in the urban regeneration process. Vilches, Barrios Padura, & Molina Huelva, (2017) have improved a methodology to choose the most appropriate retrofit measure in a context of fuel poverty.

These new scenarios of investigation require that future built environment professionals have to acquire new cognitive skills. Thus, the need to investigate on pedagogical aspects for developing abilities of future practitioners of the built environment is a crucial current challenge. This challenge seeks to combine social and physical disciplines with the aim of exchanging information from which new understanding can arise (Darbellay, 2015).

The trend since the 90's has been towards growth in the pedagogical aspects of sustainable development, where Higher Education has had a critical role in the process for the improvement of competences in sustainability of the built environment (Disterheft, Ferreira Da Silva Caeiro, Ramos, & De Miranda Azeiteiro, 2012) such as, working in collaboration between disciplines (Adomßent et al., 2014), as well as the ability to explore multidisciplinary problems (Dieleman & Huisingh, 2006). Therefore, the learning process has recently become more complex (Ramirez, 2012). Consequently, traditional theoretical and practical learning approaches seem to be inappropriate to deal with the emergent demands of complexity in learning (Wooltorton et al., 2015). Nevertheless, in spite of the wide recognition of the impact of these pedagogical principles of sustainability, the integration of such transformative pedagogies is often neglected and thus, there is a need to eradicate practical and institutional obstacles for the development of such goal-seeking (Jaeger, 2011).

Hence, this study deals with the development of competences of future practitioners, specifically, it presents the final stage of the first work package of an H2020-Marie-Sklodowska Curie project, which focuses on the development of an Innovative Learning Platform for Knowledge Integration in Energy Retrofit. This final stage concerns the methodological approach that was used to define the relevant information networks concerning Energy Retrofit using a cognitive mapping technique. The methodology is applied to 10 case studies in order to explore the relationships between Energy Retrofit and built environment transformation processes enhancing plurality disciplinary perspectives.

The structure of the paper is as follows. Section 2 summarizes the Transdisciplinary Energy Retrofit Conceptual Framework (TERCF) that was elaborated in an earlier phase introducing the research question and the contribution of this particular study; Section 3 describes in detail the methodological approach adopted, and; Section 4 presents the results; Section 5 discusses the findings pointing out the need of appropriate learning tools in order to promote knowledge integration for sustainable ER solutions. In the conclusion, the next steps of the research are presented.

2. Method

Table 1 shows a simplified version of the TERCF which was elaborated in an earlier phase of this research. The TERCF is a first result towards the development of an Innovative Learning Platform for Knowledge Integration in Energy Retrofit. This TERCF is based on the literature review of 213 peer-reviewed papers. Grounded Theory Methodology was adopted to identify specific transdisciplinary themes in the collected works and a cognitive mapping technique was used to represent it. Until now, the selection of papers was substantially based on theoretical works and empirical experiences, which were focused on well-defined ER topics. Therefore, case studies of built environment transformation processes, as a final product of a synergy of a multitude of ER strategies, have until this point not been taken into account.

Table 1. Contents of the TERCF

Questions	Knowledge Domains	Sub-domains	Key-concepts	General objectives
What is changing?	Low Carbon Transition	From Building Retrofit to Urban Retrofit	Climate Performance Planning	to combine effects of mitigation and adaptation measures
		Technical and Social Integration	Culture Environment Innovation	to describe drivers and barriers and sociological implications to the adoption of sustainable retrofit measures
		Disruptive and Sustainable local technologies	Calibration Consumption Options	to explore community-based energy retrofits for the practical realisation of the smart city imaginary
What do we need?	Information modelling process	Energy modelling process	Calibration Consumption Options	to integrate knowledge to an appropriate level in order to assess the impact of a diverse range of retrofit measures
		Occupant behaviour modelling	Behaviour Occupant Data	to investigate on the relationship between buildings and people through a process of 'interactive adaptation' and co-evolution of the physical and the social factors
		Life cycle analysis modelling	Assessment Forecast Performance	to integrate life cycle energy and environmental performance
How do we manage?	Decision-making process	Multi-attribute information	Cost Financial Mechanism	to take into account to uncertainties associated with the prediction analysing multi-benefit of retrofit measures
		Bottom-up methodology	Criteria Incentive Inhabitant	to follow a multi-stage development process to improving local green building features
		Economic and socio-technical factors	Economics Integration Investments	to pursue social justice reducing fuel poverty and promoting innovative financial mechanism.

Questions	Knowledge Domains	Sub-domains	Key-concepts	General objectives
What do we implement?	Innovative technical solutions	Innovative building materials	Inertia Insulation Properties	to assess the performance and the environmental impacts of life cycle insulation
		Passive, active and smart technologies	Bioclimatic Control Integrated	to define and preserve the building envelope features
		Building sector renovation	Industry Prefabricated Research	to consider the level of knowledge of local micro-enterprises and stakeholders' perspective when sustainable energy technology are promoted.
What do we implement?	Energy and environmental awareness	Integrated Community energy system	Decentralised Entrepreneurship Local	to pursue a more socially transformative pathways to sustainability involving community organisations
		Comfort and Quality of life	Instruments Policy Social	to analyse different technologies that have been adopted and their perceived effectiveness
		Socio-technological learning process	Education Experiments Networks	to improve participatory process taking into account practitioners and academic perspectives

This paper focuses on the case study analysis which is a fundamental part of this research project. Indeed, this analysis is a key instrument designed to capture multi-disciplinary information from urban contexts. This section illustrates the method that was used for selecting them and comparing the information gathered.

Therefore, the approach adopted seeks to identify a full range of values characterizing the ER concept in the context of urban transformation processes. Specifically, in this work-package (WP1), these values are expressed in the form of *List of Concepts,* which was elaborated following the cognitive mapping technique (Novak & Cañas, 2004). Subsequently (WP2) the relationships among concepts will be defined and transferred into the cognitive learning platform. This work-package was completed by following these steps:

1. Selecting case studies. Five criteria were established for the selection of the case studies: i) environmental context; ii) urban morphological condition; iii) actual building use; iv) type of construction; iv) level of protection/ legislative framework. Therefore, each case study is representative of a specific combination of the above-mentioned criteria. More details on the selection criteria are provided in the next section.

2. Identifying main topics. A textual report was used to present each case study. Specifically, for each case study one and only one relevant topic was identified. In terms of cognitive mapping technique, this means to define a *Focus Question* and to propose a *main concept* as a starting point for the analysis. Many aspects of the Energy Retrofit cases were thus identified.

3. Coding list of concepts. After identifying main topics, the cognitive mapping technique was applied to the textual report. As a result, a *List of concepts* for each case study was elaborated. These lists became the bases to build a multitude of relationships between the Energy Retrofit case study and the urban context examined.
4. Comparison and hierarchical organisation of the concepts. The concepts listed were compared, synthesised and re-organised in order to structure the information, and then, transfer them into the TERCF. Similar, repeated or synonymous concepts, were excluded from the combined list. In addition, the most general and inclusive concepts were positioned at the top of a concept map with the more specific and exclusive concepts arranged hierarchically below. As a result, a preliminary hierarchical structure was defined. Thus, a *Unique List of concepts* was developed.
5. Linking with the conceptual framework. Finally, the concepts were allocated to the appropriate categories and sub-categories of the conceptual framework developed in the first step of WP1 in order to reinforce the contents of the TERCF. This is a preliminary allocation, which will be finalised at the end of WP2

2.1 Case Selection

Case Selection is the primordial task of the case study researcher in which the problem of representativeness cannot be ignored. Seawrigh and Gerring (2008) have pointed out that scholars continue to lean primarily on pragmatic considerations about *Case Selection* such as time, money, expertise, and access. They state these are perfectly legitimate factors in case selection, but they do not provide a methodological justification. Consequently, in agreement with Seawrigh and Gerring (2008), the essential issue about *Case Selection* is that researchers understand how the properties of the selected cases compare with the rest of the population (Seawrigh and Gerring, 2008).

To date various methods have been developed and introduced to select case studies. Specifically, this work adopts the *diverse case method* (Seawright & Gerring, 2008)[1].

This method facilitates the achievement of maximum variance (i.e. maximum variance on ER concepts) along relevant dimensions (i.e. dimensions of urban transformations).

Seawright and Gerring explain how *diverse case method* works: ["*It requires the selection of a set of cases, at minimum, two, which are intended to represent the full range of values characterizing X, Y, or some particular X/Y relationship*[2]*. The investigation is understood to be exploratory (hypothesis seeking) when the researcher focuses on X or Y and confirmatory (hypothesis testing) when he or she focuses on a particular X/Y relationship*] (Seawright and Gerring, 2008, p. 300).

The criteria for case study selection were established such that relevant information could be gathered to identify the key concepts, which could then be used to further elaborate the TERCF. The choice of the criteria is justified using relevant literature

[1]Seawrigh and Gerring present other case selection techniques as Typical Case method and Extreme Case method. The former "[…] focuses on a case that exemplifies a stable, cross-case relationship. By construction, the typical case may also be considered a representative case, according to the terms of whatever cross-case model is employed." (Seawright and Gerring, 2008, p. 299). The last "[…] selects a case because of its extreme value on the independent (X) or dependent (Y) variable of interest. An extreme value is understood here as an observation that lies far away from the mean of a given distribution; that is to say, it is unusual". (Seawright and Gerring, 2008, p. 301).

[2] In this study X are energy retrofit concepts and Y are urban contexts

which highlights the importance of adopting a transdisciplinary approach to environmental design in achieving higher echelons of urban sustainability.

The first criterion (Environmental context) seeks to reflect the range of "environmental conditions" around Europe. Specifically, this criterion involves several relevant factors (e.g. temperature, humidity, solar and wind exposure). Indeed, the environmental contexts and buildings' energy efficiency are interlinked issues in terms of climate adaptation strategies (Biesbroek et al., 2010; Fitch, 1980). Moreover, energy efficiency of the cities is related to the urban forms (Knowles, 1974; Steemers, 2003). Consequently, the climate factors should first be considered in designing technological solutions (Olgay, 1969; Sadineni, Madala, & Boehm, 2011).

The second criterion (Urban morphological condition) points out how cities are different in terms of their urban structure. For example, Hang, Sandberg and Li, (2009) have investigated the effect of urban morphology on wind conditions.(Wong et al., 2011) have evaluated the surrounding urban morphology on building energy consumption.(Sarralde, Quinn, Wiesmann, & Steemers, 2015) have analysed the solar energy and urban morphology interaction in order to assess the scenarios for increasing the renewable energy potential of neighbourhoods. It is thus clear that the urban morphological features modify the general environmental conditions. Consequently, the detailed understanding of the environmental conditions in which buildings operate is a second fundamental step that characterizes the environmental design approach.

The third criterion (actual use) refers to the cost of reusing a building, both in terms of financial investment and its potential to accommodate new uses.(Shipley, Utz, & Parsons, 2006) have examined the business of heritage development, which consists of building renovation or adaptive reuse, in order to determine the success factors. They state that some reuse projects are more costly than new building, but not all, and the return on investment for heritage development is almost always higher. Similarly, (Langston, Feng, Yu, & Zhao, 2008) investigated the issue of building reuse in terms of investment by the construction sector. Instead, (Martín, Mazarrón, & Cañas, 2010) have analysed the environmental advantages of reusing abandoned rural buildings and the compatibility of old building structures with the contemporary human need. Thus, the ER requires an accurate analysis in terms of use and reuse of buildings. Their environmental, social and economic sustainability also characterize the environmental design approach.

The fourth criterion (type of construction) concerns the energy performance of the building fabric. It is also related to the age of the building and to the traditional or innovative construction technologies. On the one hand, this criterion underlines the relationships between the quality of the construction and the energy performance. For example,(Cabeza, Castell, Barreneche, De Gracia, & Fernández, 2011) have evaluated the thermal behaviour of the alveolar brick construction system, compared with a traditional Mediterranean brick system with insulation.(Cerón, Neila, & Khayet, 2011) have tested the use of phase change materials (PCM) and their possible architectural integration in the search for optimizing energy efficiency in construction. On the other hand, more recent approaches to Life Cycle Analysis have expanded the factors under investigation.(Cellura, Guarino, Longo, & Mistretta, 2014) have explored the ecological impact of the building materials introducing the life-cycle perspective by the concept of

energy balance, which includes the embodied energy of a building and its components. Hence, the strengths and weaknesses of different construction technologies from an energy and environmental perspective, is another characteristic of the environmental design approach.
The last criterion takes into account the level of protection/ legislative framework. It considers the range of the level of protection (i.e. from without restriction to listed buildings). As well known, e European Union has enacted several directives dealing, directly and indirectly, with energy efficiency in buildings in order to reduce energy use. However, individual countries can adopt their own rules to include or exclude buildings from respecting the energy efficiency requirements for existing buildings. Consequently, so far, no general rules, codes or standards are available for energy retrofit of historical and architecturally valuable buildings (Mazzarella, 2015). (Martínez-Molina, Tort-Ausina, Cho, & Vivancos, 2016) presented an extensive overview of the literature surrounding this topic, summarizing the different methods and techniques that have been used around the world to achieve higher energy performance through refurbishment. They have demonstrated the feasibility of maintaining heritage values of historic buildings while achieving significant improvements in their energy efficiency and thermal comfort. (Fabbri, Zuppiroli, & Ambrogio, 2012) have investigated an evaluation and measurement tool for town energy consumption, which is related to the age and the characteristics of existing buildings. They have underlined how this problem concerns both urban planning and architectural heritage disciplines. Therefore, the environmental design emerges as a relevant approach, particularly for the old cities of Europe, to understanding how the strategies for Energy Retrofit can be diversified in relation to the historic and social stratifications at different locations.

3. Results

This section presents the main results.

3.1 Selected Case Studies

Table 2 shows the 10 case studies selected.

Table 2. List of the 10 case studies

Context	Use	Date	Construction Technology	Level of protection
Austria	Mix	1940-1950	Masonry	no
Belgium	Social housing	1957	Reinforced concrete	no
France	Commercial building (Former industrial site)	1800	Steel and Wood	no
Germany	School	1966	Exposed concrete	no
Italy	Library (Former industrial site)	1971	Prefabricated concrete	no
Malta	Office	1800	Masonry	Listed Building
Norway	School	1914	Cavity brick walls (without insulation)	Listed Building
Spain	Social housing	1967	Reinforced concrete	no
Sweden	Social housing	1970	Reinforced concrete	no
United Kingdom	Family house	1890	Solid Brick wall	Listed Building

3.2 Identifying Main Topics

Table 3 shows the contribution of each case study in terms of *Focus Questions* and *Main Concepts*. Findings may be considered representative of relevant issues concerning ER in the urban context, although they are not exhaustive.

Table 3. Definition of the Focus Question and individuation of the main concept for each case study

Case study	Focus Question	Main Concept
Austria	What strategies to innovate energy infrastructure and buildings?	Micro-net
Belgium	How to increase the social impact of ER actions?	Active participation
France	How to enhance the relation between architecture and citizens?	Functional programme
Germany	How to manage energy consumption?	Energy Consumptions
Italy	How to integrate bioclimatic strategies?	Modest transformation
Malta	How to increase the efficiency and ecology of building plant systems?	Cooling system
Norway	How to improve the performance of the building envelope?	Building envelope
Spain	What strategies to reduce energy poverty?	Profiles of Energy poverty
Sweden	How to deal with the level of uncertainties?	User-oriented approaches
United Kingdom	What strategies to reduce carbon emissions?	Legislation to reduce carbon emission

3.3 Coding List of Concepts

The results obtained from the preliminary analysis of each case study can be compared in table 4. Interestingly, only about 12% of repetitions were observed. Thus, the result indicates that each case study provided a specific relationship between ER and Urban context.

Table 4. List of concept collected

Case study	List of concepts	N. concepts
Austria	Urban quality, District heating Integrate renewable energy in existing, Supply system, Renewable energy, Heat pump, Solar collector Micro-net, Planning directives Detailed simulation, Decision-making- process, Social aspects of retrofit, Reduce heat demand, Building physics, Vacuum-panels, Air ventilation system, Minimize overheating, Optimized active cooling system, Information point; Tenants behaviour;	20
Belgium	Residential character; Artistic expression; Balanced choice of materials; Environmental performance; Aesthetics; Improve the comfort of the inhabitants; Limate the energy costs of the tenants ; Passive design; Reduce the environmental footprint; Thermal bridges; Breaks the monotony of the facades; Artistic intervention ; Materials are chosen without organic volatile compounds (vocs); Thermal insulation; Ventilation; Habitability;	16
France	Ecological aspect; Relation between architecture and citizens; Improve the quality of life; Promote the awareness; Need and requirements of the local population; Recyclable material; Diversified functional mix; Production from renewable sources; Recovery of heat; Geothermal energy; High thermal-acoustic properties; Rockwool; Thermal inertia ; Ensure summer thermal comfort; Highly populated building; Prefabrication as Innovative technology; PV panels;	16

Case study	List of concepts	N. concepts
Germany	Heat consumption ; Indoor environmental quality; Pvc-framed double glazed windows; Windows of single glazing; U-values ; Building envelope; Ventilation systems ; Mechanical ventilation; Cogeneration plant (CHP) ; Heat demand; PV Modules orientated ; Cross air flow Decentralized ventilation units ; Heat recovery; Reflection factors ; Monitoring; Indoor air quality ; Monitoring technology; Communication technology;	17
Italy	Development and progress of this city; Economic dynamics; Political vision; City's cultural life; Architectural expression; Light capture Natural ventilation systems; "Sun chimneys"; Low-emissivity glass; Natural lighting; Natural difference pressure; Air extraction; Administrative needs;	13
Malta	Night time convective ventilation (passive night cooling); Passive downdraught evaporative cooling system (PDEC). Direct cooling; Indirect cooling; Thermal comfort; Well-being; Save on the use of artificially generated energy; Control the relative humidity in the air; Thermal performance; Adaptability Protected building; Building Management System (BMS); Bioclimatic strategies; Passive systems; Active systems;	15
Norway	Space heating system; Ventilation system; Sanitary hot water system; Electric lighting system Renewable energy system; Management system; Passive solar gains; Avoid glare; Overheating; Geothermal energy source; Avoid moisture; External insulation; Buildings' aesthetics; Long life expectation ; Affordable operational and maintenance costs; Building energy management system (BEMS); Space heating control; Ventilation control; Lighting control; Monitor the energy consumption;	20
Spain	Job creation; Retrieve industrial and professional activity ; Construction sector; Energy bills; Health risk conditions; Geographic concentration of obsolete buildings ; Vulnerability; Risk of exclusion; Neighbourhood; Financial mechanisms; Economically feasible projects; Payback in reasonable timing; Energy services companies; Representative groups; Low-income families; Influence of compactness; Economic aspects; Social aspects; Real estate market;	18
Sweden	Living standards; Active participation Preheating domestic hot water ; Fresh air preheated; Greenhouses; Prevailing winds; Communal greenhouses; Heat recovery; Thermal conduction; Extra layer of thermal insulation and a cavity; Low-emission panes; Occupancy sensors; Metering systems; Climate-oriented design approaches; Uncertainties; Building's lifetime ; Household appliances; Occupant behaviour; Maintenance support; Climatic conditions;	20
United Kingdom	Insulation; insulation; Wood Fibre Insulation; Rotex Combined Gas-Solar Unit; Solar Thermal Panels; Mechanical Ventilation; Triple Glazed Windows; Air Permeability; Systems Can Operate In Conflict; Consumption; Differences Between Forecast Consumption And Actual Use; Errors on The Initial Forecast Model; Differences In Expected Occupant Use; Energy And Actual Use; Monitoring Methodology; Fabric Performing; Low Carbon Systems Performing; Use Of The Building By Occupants; Predict Performance; Energy Systems use On A Month To Month Basis;	20
	Total concepts	157

3.4 Comparison and Hierarchical Organisation of the Concepts

In Table 5 the *Unique List of concepts* is shown.

Table 5. *Unique List of concepts* based on a hierarchical distribution of the concepts

Preliminary Hierarchical Structure

I level	II level	III level
Micro-net	Communication technology; Supply systems; Active systems	Metering systems; Space heating system; Production from renewable sources; Systems Can Operate In Conflict; Household appliances; Maintenance support; Space heating control; Overheating; Ventilation control; Lighting control; Cogeneration plant (CHP); Heat pump; Recovery of heat; Renewable energy system; Integrate renewable energy in existing; PV Modules orientated; Solar collector; Sanitary hot water system; Preheating domestic hot water; Geothermal energy
Active participation	Development and progress of city; City's cultural life	Planning directives; Aesthetics; Neighbourhood; Decision-making-process; Relation between architecture and citizens; Information point; Administrative needs; Buildings' aesthetics; Architectural expression; Breaks the monotony of the facades; Artistic expression; Artistic intervention
Functional programme	Climate-oriented design approaches; Geographic concentration of obsolete buildings	Climatic conditions; Protected building; Adaptability; Habitability; Diversified functional mix; Environmental performance; Protected building; Building's lifetime; Long life expectation
Energy Consumption	Indoor environmental quality; Building energy management system; Differences Between Forecast Consumption And Actual Use	Ensure summer thermal comfort; Detailed simulation; Affordable operational and maintenance costs; Heat consumption; Energy Systems use On A Month To Month Basis; Reduce heat demand; Save on the use of artificially generated energy; Highly populated building; Errors on The Initial Forecast Model; Differences In Expected Occupant Use
Modest transformation	Bioclimatic strategies; Balanced choice of materials	Passive design; Extra layer of thermal insulation and a cavity; Ventilation; Natural lighting; Light capture; Passive systems; Passive solar gains; Sun chimneys; Greenhouses;; Ventilation systems; Natural difference pressure; Cross air flow; Air extraction; Air Permeability
Cooling system	Optimized active cooling system; Air ventilation system	Direct cooling; Indirect cooling; Mechanical ventilation; Passive downdraught evaporative cooling system (PDEC); Decentralized ventilation units; Minimize overheating; Fresh air preheated; Night time convective ventilation (passive night cooling); Electric lighting system; Control the relative humidity in the air
Building envelope	Fabric Performing; Prefabrication as Innovative technology; Building Management System	Influence of compactness; Thermal comfort; High thermal-acoustic properties; Avoid glare; Avoid moisture; Materials without organic volatile compounds (vocs); Building physics; Low-emission panes; Low-emissivity glass; Thermal performance; Thermal conduction; U-values; Insulation; Polystyrene insulation; Wood Fibre Insulation; Rockwool; Windows of single glazing; Pvc-framed double glazed windows; Triple Glazed Windows; Vacuum-panels; External insulation; Thermal bridges; Thermal inertia; Reflection factors
Profiles of Energy poverty	Social aspects; Economic dynamics; Low-income families	Residential character; Economically feasible projects; Communal greenhouses; Financial mechanisms; Limate the energy costs of the tenants; Energy bills; Payback in reasonable timing
User-oriented approaches	Improve the quality of life; Improve the comfort of the inhabitants; Predict Performance	Need and requirements of the local population; Well-being; Use Of The Building By Occupants; Representative groups; Occupant behaviour; Tenants behaviour; Living standards; Health risk conditions; Monitoring technology; Occupancy sensors; Monitoring Methodology; Monitor the energy consumption;
Legislation to reduce carbon emission	Low Carbon Systems Performing; Political vision	Economic aspects; Vulnerability; District heating; Reduce the environmental footprint; Promote the awareness; Job creation; Energy services companies

3.5 Linking with the Conceptual Framework (TERCF)

The preliminary distribution of concepts within the TERCF is based on a qualitative connection between the *Main Concepts* (Table 3) and the prior concepts listed into the TERCF (Table 1). They are not static connections. Specific linking phases will be developed in the next phase of the research. In Table 6 *Main concepts* and their preliminary distribution within the TERCF is shown. Specifically, in order to justify the qualitative connections proposed some comments from the researcher are provided.

Table 6. Main concepts and their preliminary distribution within the TERCF.

Main Concept	**TERCF Concept**	**Category and Line of Research**	**Researcher's comments**
Micro-net	Decentralised	Energy and environmental awareness: Integrate Community Energy System	Micro-net is a form of decentralised energy system.
Active participation	Community	Low Carbon Transition: Disruptive and Sustainable local technologies	Active participation involves local communities
Functional programme	Instruments	Energy and environmental awareness: Comfort and Quality of life	Functional programme is an instruments to improve the quality of life
Energy Consumptions	Forecast	Information modelling process: Life cycle analysis modelling	Energy Consumption analysis is often associated to its forecast
Modest transformation	Innovation	Low Carbon Transition: Technical and Social Integration	Modest transformation is a form of innovation, which seeks to point out the main factors that generate high level of energy consumption within a specific context.
Cooling system	Integrated	Innovative Technical Solution: Passive, active and smart technologies	Cooling systems require integration strategies, enhancing passive and active strategies
Building envelope	Property	Innovative Technical Solution: Innovative building material	Building envelope performance is related to the property of the envelope components
Profiles of Energy poverty	Integration	Decision making process: Economic and socio-technical factors	Profiles of Energy poverty require integration between economic and socio-technical factors
User-oriented approaches	Behaviour	Information modelling process: Occupant behaviour modelling	User-oriented approaches is focused on users' behaviour
Legislation to reduce carbon emission	Criteria	Decision making process: Bottom-up methodology	Legislation to reduce carbon emission requires identifying the criteria on which the energy transition has to be developed.

4. Discussion and Conclusion

This paper has described the methodological approach that was used to define the relevant information networks concerning Energy Retrofit using a cognitive mapping technique. The results reveal a multitude of implications, in the form of concepts, between Energy Retrofit and built environment transformation processes, enhancing plurality disciplinary perspectives. These concepts, hierarchically organized, have been integrated into the TERCF and 10 *Focus Questions*, which involve both physical and social

science viewpoints, have been identified. These *Focus Questions* point out how the adopted methodological approach was useful for integrating diverse ER disciplinary perspectives, starting from the analysis of case studies as representative of real-problems.
Furthermore, another important finding concerns the nature of these *Focus Questions*, which focus on improving users' cognitive skills that are involved in mutual and joint learning processes. In literature there are different types of focus questions. As described by Miller & Cañas, (2008) the typology depends on two main criteria: "[…] *the degree to which a question admits a variety of answers across different individuals, that is, how open to personal input a question is;* […] *the degree to which the answer requires explanation through dynamic propositions"* (Miller & Cañas, 2008, p. 366). With regard to these two criteria the authors argue that *Focus Questions* may be classified in three main groups: Closed or Classificatory; Open-static; Open-Dynamic. In the first group, "*[…] questions tend to have a universally accepted answer and therefore do not allow much variation among respondents*; (in the second group) […] *questions generally request descriptions of concepts.* (In the last group) […] *questions generally deal with events, rather than objects, and go beyond requiring mere descriptions to demanding reasons and explanations for these events, be they situations or happenings*" (Miller & Cañas, 2008, p.366)
The 10 *Focus Questions* are proposed as open-dynamic focus questions and the *list of concepts* are suggested, in accordance with the cognitive mapping technique as *Parking lot concepts*, which is a list that suggests key concepts that may be included within the cognitive map. The rank order of these concepts will depend on the user's scope. Thus, in agreement with Novak & Cañas, (2004) *Focus Questions* and *Parking lot concepts* are fundamental to stimulate users' cognitive skills, investigating, as proposed by Safayeni, Derbentseva, & Cañnas, (2005) on dynamic relationships among concepts. These establish implications, functional interdependence and covariation among the concepts. By doing so, the investigation among potential dynamic relationships may be considered as a meaningful learning activity in a context of multi-disciplinary learning activities with the aim of improving skills and competences of the future built environment professionals through a continuous exchange of perspectives.
In conclusion, the present study was designed to augment the TERCF by including the concepts that emerged from the case study analysis. The main goal of this phase of the study was to determine *Focus Questions* and the *Main Concepts,* which were useful for representing relevant issues concerning Energy Retrofit in the urban context. Therefore, this research extends our knowledge of a multidisciplinary approach in Energy Retrofit. Nevertheless, the most important limitation lies in the fact that the results of this phase did not show the relationships among concepts. Consequently, further experimental investigations are needed to establish these relationships. In the next phase of the research, the case studies will be translated into cognitive maps. Subsequently, each relationship proposed in the TERCF will be defined in order to develop a learning platform for knowledge integration in Energy Retrofit.

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