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A meaningful mapping approach for the complex design.

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Developing the ability to manage complexity has become an essential element for the training of designers. In such a context, complexity mainly arises from the need to integrate knowledge and expertise. The project is grounded in a hypothesis of systematizing Meaningful Learning Activities with computer applications dedicated to the elaboration of cognitive maps, in order to develop the ability to manage the complexity of high-interaction flows which can be found in the project of energy efficiency in historic buildings. This paper focuses on two experimental courses, with the aim to assess the formative approach adopted. The results highlight an innovative procedure and a tool helpful both to trainers and to learners to assess and direct the quality of the complex design process.

Keywords: information processing; design education; design knowledge

1 Introduction

Complexity is one of the main feature of contemporary society [31]. With the introduction of environmental components in designing, the complexity level has exponentially increased. A high complexity example is represented by the project of energy efficiency in historic buildings. It requires the development on the one hand, of interdisciplinary communicative ability and deep disciplinary technical skills and, on the other hand, of designing creativity able to set solutions compatible with significant historical traces.

Globally, and in particular in Europe, research on historic buildings energy efficiency is recognized as both timely and of central interest [20]. Integrating knowledge as the principal strategy for promoting and developing the identity and energy performance of existing buildings has been a common theme in previous EU-funded research (e.g.: 3encult, 2010–2014; Governee, 2010–2013; Sechurba, 2008–2011; New4old, 2007–2010; Brita In Pubs, 2004–2008; Recite/Rebuild, 1993–1995).

Some studies focus on engineering and architectural interactions through the integration of innovative systems to reduce energy demand [53], some on evaluating the feasibility and compatibility of renewable energy systems in existing buildings [1]. Other research evaluate how the new technologies can valorise the environmental components within the design strategies [57], or support the life cycle approach to select the most effective options during design and implementation [3]. In addition, some research has investigated non-technical issues such as the progress made on energy regulations for buildings in relation to implementation, development and compliance [21], or investigating governance [50] and the development of sustainable energy communities in urban areas [47].

What emerges from the state of the art review is a call for the education and training of practitioners who interact on integrated projects as the first step in dealing with complexity inherent in historic buildings energy efficiency. It is an acknowledgement of the need for integration. But, it completely oversees the urgent need to revolutionise the traditional, rote-learning approaches to education and the significant role an innovative approach to educate future practitioners could play to make integration a common practice [10].

The cognitive approach is the starting point. It emerged in the field of psychology [5,6] and has brought about innovation in educating and training designers. Researchers have studied its various aspects in this context, including the importance of organizing and managing knowledge [32,27]. Project knowledge has drawn attention through the exploration of the way a student succeeds in developing meaningful concepts with the help of appropriate learning tools [17]. Others [39, 43] have concentrated on training designers through the use of cognitive maps and their ability to structurally represent knowledge. Here, the need to follow a procedural logic and to have suitable tools to effectively support the knowledge process, and the development of technical skills and creative capacities are regarded as keys to success.

There are two important limitations in adopting one of these approaches in the field of historic buildings energy efficiency. Firstly, the knowledge process in design substantially focuses on the development of individual skills and neglects the collaborative task. Secondly, the learning environment is overlooked as the creative ability of the individual takes precedence. In the historic buildings energy efficiency context, both collaborative task and learning environments are important. Creativity comes about when collaboration is nurtured in such environments that engage the learners in the knowledge process.

Constructing these environments, and therefore abandoning rote learning forms, is challenging [33]. Implementing the cognitive approach through a series of meaningful learning activities, which are derived from the Meaningful Learning Theory [4], is a possible solution. It can increase the quality of the integrated knowledge paths by working through concepts and connections drawn from individual and collective prior knowledge [9]. In particular, Novak has argued that cognitive maps are able to support the meaningful learning activities by working through concepts and connections that can be manipulated, organized, focused, contextualized and discussed [34]. With his guidance, the research group of the Cornel University Cognitive Machines Department has developed "Cmap tools", a free software recently extended in the cloud version. It is a software that permits the computerized processing of cognitive maps by systemizing a complex set of functions [35]. These innovative functions empower a user or a users' community to easily manage the information flows, giving meaning to concepts and their relationships. The software supports the cognitive approach since it aims to describe how information is organized and processed, thus emphasizing more the process than the product [30].

Starting, therefore, from the fact-finding achievements of the European programmes, this paper focuses on the development of an advanced educational approach founded substantially on a novel application of cognitive maps [34,35,36,37] and meaningful learning activities [22,23,24] in designing technological solutions for historic buildings energy efficiency.

1.1 Research questions and novelty in design education

The main objective of this work is to develop a cognitive instructional design in the field of historic buildings energy efficiency. In particular, the very objective is to assess the effectiveness and efficiency of the formative approach adopted both as procedure and assessment tool of the learning quality from the trainer's point of view, and as development of innovative cognitive abilities from the student's perspective. In this way, new research questions are raised:

1 Does the use of a software based cognitive thinking tool result in equivalent or superior generation of cognitive ideas, problem solutions, and determination of the interconnections among various concepts regarding historic buildings energy efficiency?
2 In what specific way does a concept-mapping tool enhance the learners' ability to familiarize with key concepts and to understand how different concepts relate to one another?
3 How do design teachers relate and react to new cognitive-oriented learning affordances?

This study establishes an important step towards an innovative learning platform as well as a new approach to train practitioners really inclined to improve the energy performance of the existing buildings through an interdisciplinary collaboration. The key innovation is the exploitation of various features of a meaningful mapping approach in order to develop an agile and sustainable learning platform. These features include the ability to:

- switch from highly complex models to simplified ones, according to the level of the users' knowledge;
- be adapted and transformed for a continuous use, depending on the users' needs;
- be implemented and updated, through the users interaction.

This approach is novel at different levels. Firstly, it provides a concrete contribution towards dealing with integration and complexity issues in energy retrofit by developing a platform which will enable its users to transcend the professional silos and to improve their skills to manage complexity. It aims to compensate for the lack of educational programmes dedicated to the interdisciplinary learning, which helps develop the ability to transfer information and knowledge beyond the disciplinary boundaries, and to investigate the tensions among the social, economic, environmental and technological dimensions of sustainability. Secondly, it increases and, for the first time, integrates the existing knowledge in three relevant disciplines, e.g., energy retrofit, cognitive psychology and pedagogy, in order to solve the societal problem of reducing the demand for energy. Thirdly, it takes on a longitudinal approach to training and education by testing and evaluating the platform with users with different levels of prior knowledge and experience, e.g., undergraduate and postgraduate students, and practitioners. It also offers the opportunity for the outputs to be exploited in universities of different countries. Fourthly, it utilises the cognitive approach to nurture creativity in a collaborative setting as opposed to the individualistic design process.

In order to answer the above-mentioned research questions, the research project has: developed some specific tools for training; planned a series of meaningful learning activities; organized interdisciplinary experimental courses to test hypotheses and tools.

This paper focuses on two experimental courses, both international and interdisciplinary, belonging to an European research project. The former addresses 20 trainers involved in various capacities in the project

of energy efficiency in historic buildings; the latter addresses 20 selected students and concentrates on the interdisciplinary dialogue and group work.

In the following sections, this paper will first illustrate the methodological approach adopted. In particular, the development of the didactic tools will be described in detail in order to highlight the whole process in which the procedure reliability and validity are grounded, and to communicate its adaptability and transferability to other topics. Then, the qualitative and quantitative outcomes collected from these didactic experiments will be presented.

After discussing the results, this study will provide an interesting insight into the innovative aspects of:

- educational outlines dedicated to spreading the dynamic and interactive knowledge of preservation and sustainability;
- learning process mainly founded on interaction, creativity and critical use of technology, these being the essential elements of the project of energy efficiency in historic buildings;
- instrumental frameworks supporting training, trough dynamic cognitive systems able to simplify technical and non-technical information concerning historic buildings energy efficiency.

2 Research method and tools

The methodological approach adopted is essentially based on a hypothesis of systematizing the meaningful learning activities with computer applications dedicated to the elaboration of cognitive maps in order to develop a cognitive instructional design in the field of historic buildings energy efficiency.

This is an explanatory research, which helps determine the best research design, data collection method and selection of subjects in the field of the complex design training. In this work this work has opted for a combined qualitative and quantitative approach with particular reference to the previous experiences about the semi-automatic and automatic construction of concept maps from texts. These experiences have employed morphological, syntactic and statistical analyses of the concept maps in order to improve an ontological innovation in the field of historic buildings energy efficiency. The approach is still under implementation.

Before presenting the organization of the research work, for a greater comprehension of the approach adopted it is useful to make some preliminary methodological remarks about the meaningful learning activities and the mapping software. These preliminary remarks intend to highlight how this study aims to develop the ability to create questions, this being an important activity for the quality of a designing path. Nowadays, the methodological problem is significant: as underlined by De Biase [11], human beings are better than machines at raising questions, but the speed of technological innovation and the computerization of the devices monitoring the complex design are undermining such a skill.

Therefore, this ability has to be not only preserved but also developed. Through its enhancement, it will be possible to emphasize the best possibilities offered by the man-machine interaction.

Hence, the association of the meaningful learning activities with the cognitive mapping software in the project of energy efficiency in historic buildings means building the methodological and instrumental bases to face the challenge of training in the complex design.

2.1 The five meaningful activities and Cmap functionality

First, it is important to point out that there are several approaches to the meaningful learning activities and several mapping software too. In this work, there is a fundamental methodological reason behind the choice of specific references. With regard to the meaningful learning activities, this study refers to the description proposed by Jonassen [24] since, differently from other studies [25,13], he considers intentionality (intentional) the distinguishing activity of his meaningful approach (the other four activities are the same for the various mentioned authors). In particular, compared to other features, intentionality is also the main element characterizing "CmapTools" software. Indeed, a comparison of the software packages that support cognitive (e.g., "CmapTools"; "Qiqqa"; "Mindomo") and mind mapping (e.g., "Edraw", "MindMap", "Coogle") shows that "Cmap tools" constitute the most appropriate open source package in this context . In contrast with mind mapping packages that produce tree diagrams originating from a single key concept, "Cmap tools" produce cognitive maps that represent some suggested relationships between concepts, thus elaborating complex networks of knowledge. The maps can be processed by deploying a different set of functions in a computer environment [37].

These functions, which are illustrated in Figure 1, are not present in other software. The knowledge path originates from the focus question. The hierarchical organization of the domains of knowledge is achieved by capturing ideas as short phrases, appropriately linking phrases of text to express their relationship with one another and simultaneously visualizing as text and map. Other information (e.g., videos, images, text, url links) can also be associated with the map components, augmenting basic information. The tools can be used individually or in collaboration; on-line through the Cmap-cloud or off-line.
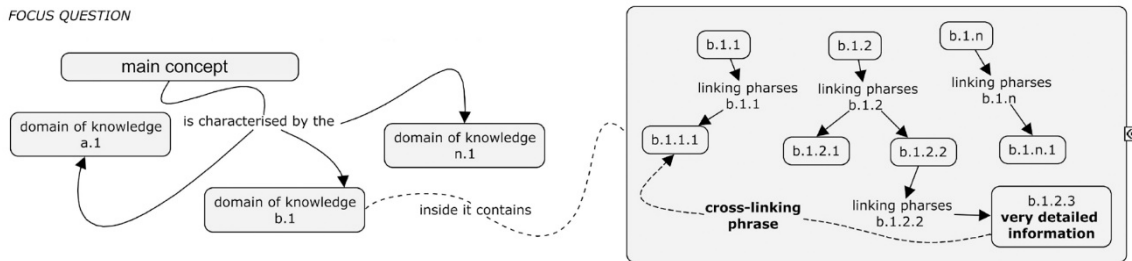
Figure 1. "CmapTools" main functionalities. According to the Novakian style, the figure represents the mapping technique used to build a preliminary ontology on historic building energy efficiency

It is useful a synthesis of the meaningful learning activities and the "Cmap Tools" software main functions underlying this research experience.

The five meaningful activities. This sub-section presents the activities characterizing the meaningful learning. Such activities are non-sequential, often overlapping and rich in feedback. They let us give sense and value to information; they are individual and collective activities, and concern different phases of the knowledge process. According to Jonassen et al [22], the meaningful learning activities are so

divided: observant and manipulative; constructive and reflective; intentional; complex and contextual; collaborative and conversational.

It is worthwhile having a deeper glance at these activities:

- Observant and manipulative activity: the meaningful learning requires "learners" who are active and actively engaged in a meaningful task whereby they can manipulate objects and parameters and observe the results of their manipulation.
- Constructive and reflective activity: activity is essential but insufficient for the meaningful learning. It demands "learners" to articulate their activities and observations and reflect on how to integrate prior knowledge with new information.
- Intentional and goal-directed activity: human behaviour is naturally goal-directed. When actively trying to achieve a learning goal they have set, students think and learn more. In order to experience the meaningful learning, they must be able to set their own learning goals and monitor their own progress.
- Complex and contextual activity: thoughts and ideas rely on the contexts in which they occur to acquire meaning. Presenting facts stripped of their contextual clues separates knowledge from reality. Learning is meaningful, better understood and more likely to be transferred to new situations when it occurs by connecting with real-life and complex problems.
- Collaborative and conversational activity: the meaningful learning requires conversations and group experiences. To experience the meaningful learning, students should do much more than simply access or seek information, they need to know how to examine, perceive, interpret and experience information.

Table 1 shows the difference between other software highlighting inputs/main meaningful activities/outputs.

Table 1. Comparison between some mapping software highlighting: inputs/main meaningful activities/outputs.

Input	main meaningful activities	Outputs	Cmap tools (Free)	Coggle (limited to 3 free maps)	Mindomo (limited to 3 free maps)
Focus Question	Intentional and goal-direct activity	Design Problem Focusing	●	-	-
List of Concepts	Constructive and manipulative	Prior Knowledge involvement	●	●	●
Linking Phases	Constructive and reflective	Organized and structured knowledge building	●	-	●
Domains of knowledge			●	-	-
Didactic tools	Complex and contextual activities	Collaborative work activation	●	●	●
	Collaborative and Conversational	Assessment tool	●	-	-

Cmap functionality. The cognitive approach requires appropriate tools. "Cmap Tools" has a set of functions aimed to develop the meaningful learning activities. The software functionality is described in various essays [8, 36, 37]. Below, the main functions are illustrated and summarized in relation to the purposes of this paper.

- Information gathering: each investigation begins with a focus question. The focus question defines the point of view. The software is structured to allow the processed file to be always associated with a focus question which determines the information gathering.
- Predicting outcomes: the investigation is carried out by attempting to assemble the concepts coherently with the focus question. The software permits to register different moments providing feedback until the achievement of the optimal connection.
- Creative knowledge building: the optimal connection among more concepts raises the issue of organizing the information flows. This occurs by configuring a hierarchical structure. The software has different elements useful to set up the concepts hierarchy.
- Articulating a meaningful discourse: depending on how concepts and linking phrases have been hierarchically organized, the map suggests a series of propositions. Therefore, the propositions sequence develops a meaningful discourse in response to the focus question. The software enables users to visualize the map textual form facilitating the logical control of the propositions just built.
- Social interactions and identity building: the software promotes the collaborative work, social interactions and the contents customization. It has some specific functions for the shared work. With the cloud version it is possible to simultaneously operate on the same map, also at a distance.
- Modelling conceptual changes: the maps so built are always adaptable and modifiable in relation to the users' needs.
- Constructing visual representations: the map produces an image of knowledge upon a determined conceptual issue. The map works in the same way as human brain, using images and associations to develop a discourse. In this way, the software allows the association between concepts and computer contents such as videos, photographs, sketches, texts and websites.
- Assessment resource for both teachers and students: the software enables the reading of a data set potentially useful to monitor the developed cognitive path.

2.2 Research phases

This paper describes the following project phases:

- preparatory phase of information gathering, which explains the procedure of gathering technical and non-technical information about energy efficiency in historic buildings, pointing up the high variety of information coming from case studies in real urban, social, economic and technological contexts.
- development of didactic tools and "Eh-cmap-00" guidelines, which illustrates the process of transferring information from a textual to a map form, the organizational structure of information and the guidelines for the use in the project of energy efficiency in historic buildings
- method and tools testing. Two different types of intensive courses, made up of 25 activity hours, have been organized, one addressed to trainers and the other one to students. Both courses have been international and interdisciplinary, representative of complexity of the project of energy efficiency in historic buildings and based on the collaborative work.

Now, it is helpful to explain in-depth some significant elements regarding these phases.

In relation to the experiment conducted, which is the main study object of the present paper, the exercises planned, the tools employed, the objectives and the expected results will be carefully scrutinized.

Preparatory phase: gathering information. The preparatory phase is articulated in two distinct parts: the analysis of the state of the art and that of the case studies. Both parts have contributed to the information gathering which will be systematized in the phase of the development of new didactic tools. The former aims to underline the state of the art of energy efficiency in historic heritage inside the European context; the latter wants to bring out the objectives, strategies, modality and fields of action. In particular, the cultural and technological approach to energy efficiency in historic buildings, in five different European countries (e.g., Croatia, Italy, Malta, Portugal, Spain), has been intended to analyse several cultural orientations on such a topic as well as the current policies of implementation of the European directives. Later, 25 case studies have been examined as textual report in order to

systematically gather technical and non-technical information able to illustrate the level of the experimentation implemented in the field of the historic buildings energy efficiency (Table 2).

Table 2. Data source: 25 case studies

Case study	Keywords
1878 Hostel Faro,Faro, Portugal	Thermal inertia; Natural ventilation; Solar panels
Consulado-general do Brasil Faro, Portugal	Thermal inertia; Natural ventilation; Roof Insulation
Museu de Portimão, Portimão, Portugal	Pre-cooling by river water; Natural light; Passive measures
Cineteatro louletano, Loulé, Algarve, Portugal	Lighting systems; HVAC system; Photovoltaics sources
Santa Maria do Bouro convent, Terras do Bouro, Portugal	High thermal inertia; gardens; temperature control
Monastery of Santa Maria, Conca de Barberà, Spain	Monastery; Rehabilitation; Energy Efficiency
The dominicos school convent, Alcalá de henares, Spain	Reuse of water, Solar collectors; Climate control system
San Telmo palace, Seville, Spain	Rehabilitation; Use of daylight; Wastewater disposal
Charles V palace , Granada, Spain	Heritage, Environmental Conditioning; Special Protection
Bibliotheca Hertziana, Rome, Italy	Glass facades; Albedo-reflection coefficient; Solar shading
Palazzina della Viola, Bologna, Italy	Use of local material; Overshadowing; Bioclimatic use of vegetation
Palazzo d´accursio , Bologna, italy	External walls insulation; Artificial Lightning System; Motorizing, automation and control
Public Weigh House, Bolzano, Italy	Energy retrofit, Romanesque style, monitoring.
Palazzo Venisti, Capurso, Italy	Public sector; Life Cycle Analysis (LCA); Architectural integration
Town Hall Sammichele, Bari, Italy	Integrated energy efficiency; Public sector; Architectural integration
Città dell'Altra Economia, Roma, Italy	Landscape characteristics ; Functions regeneration ; Bioclimatic Analysis tools; Solar Access; Wind Access
Palazzo delle esposizioni. Roma, Italy	Restoration; Integration; Glasshouse; Solar shading
Villa torlonia theatre, Roma, Italy	Protected buildings; Conservation principles; Plant engineering integration; Energy requirement
Ghella offices, Roma, Italy	Built fabrics; Renovation of modern architecture; Plant engineering integration; Energy optimisation of enclosure
Žitna kuća, Karlovac, Croatia	Energy efficiency; Heating/Cooling; Renewable Energy;
Green Castle LuŽnica, Zaprešić, Croatia	Geothermal Energy ; Lighting; Awareness-raising; Lower emission of CO2
French Pavilion, Zagreb, Croatia	Exhibition space; Steel load-bearing structure; Cylindrical single-space structure; Modern conception; Natural light
Natural History Museum, Dubrovnik, Croatia	Installation heating/cooling system; Installation of Led lightning Windows substitution
Xrobb l-Għaġin Centre, Marsaxlokk, Malta	Solar Energy, Wind Energy, Reuse of water, Environmental Education.
Malta Stock Exchange, Valletta, Malta	Passive evaporative cooling; Monument-box; Historical conservation; Architectural transformation;; Innovative materials

The report of the case studies has been carried out in the form of data sheet setting the information gathering on the same index structure. The main purpose has been to facilitate the diachronic reading

between the different cases. In particular, the data sheet has been introduced by key words (for example in the "Bibliotheca Hertziana" case study: Technological integration, Glass facades, Natural lighting, Albedo / reflection coefficient, Solar shading); then, within this data sheet, some information has been collected to delineate the climatic-geographic and the historic-architectural context. A specific section has been dedicated to the legislative framework in which the intervention has taken place, underlining how different countries have adopted diversified approaches to the preservation of the architectural and urban heritage and to the enhancement of the energy performances too. Every single case study has been investigated through an in-depth knowledge of the distinctive features evolution in urban, functional and architectural terms. At the end, the analysis has concluded by describing the intervention of transformation implemented. In such a way, particular emphasis has been laid on the objectives (e.g., Control of light pollution) and the strategies put into action (e.g., Control of radiation affecting the buildings transparent surfaces during the summer period using selective glass and sun shielding systems.)

Table 3 shows a selection of 5 case studies in order to provide the traceability of the data source used for the didactic tools development.

Table 3. Selection of 5 case studies and synthesis of the relevant information collected

Case study (selection)	Keywords	Main topics
1878 Hostel Faro, Faro, Portugal	Thermal inertia Natural ventilation Roof Insulation Solar panels	Minimum possible changes, maximizing the use of space for the new functions; Sustainable intervention, both in terms of construction and in terms of operation and maintenance in the short / medium term; Saving resources, particularly energy for lighting, air conditioning and heating hot water; Thermal comfort in the rooms; Integration between new technological improvements and the existing building.
Royal Monastery of Santa Maria De Poblet Conca de Barberà Spain	Monastery Rehabilitation Energy Efficiency	Use the stone walls of high thermal inertia; Use the courtyards and gardens as elements to regulate temperature; Harnessing the surface parking and roof of the monastery to produce photovoltaic energy; Use the garden and towers to capture wind energy.
Bibliotheca Hertziana, Rome, Italy	Technological integration Glass facades Natural lighting Albedo / reflection coefficient Solar shading	To protect the building's and urban fabric's historical, architectural and aesthetic values; To ensure the correct use of spaces for different categories of users; To guarantee correct lighting of reading areas; Control of light pollution; Integration between the new building's volumes and pre-existing volumes in order to obtain a building able to satisfy functional requirements while fully respecting the building's historical, architectural and cultural characteristics; Construction of a central light shaft; Re-organisation of internal spaces with consequent reorganisation of functions; Control of radiation affecting the building's transparent surfaces during the summer period through the use of selective glass and sun shielding systems.
Žitna kuća, Karlovac, Croatia	Energy efficiency Heating/Cooling Renewable Energy Geothermal Energy Awareness-	Reduction of energy consumption and peak energy use; Reduction of energy losses; Insurance of comfort and interior well-being; Maximum reduction of the environmental impact; Integration between new technological improvements and the existing building; Reconstruction of building with new materials but in the "original spirit"; Energy efficiency measures were

	raising Lower emission of CO2	implemented introducing energy efficient facade and heating system
Malta Stock Exchange, Valletta, Malta	Passive evaporative cooling Monument-box Historical conservation Architectural transformation; Innovative materials	Control the relative humidity in the air; Save on the use of artificially generated energy; Ensure thermal comfort and working environment well-being; Possibility to eventually remove parts or the whole interior structure; Create a modern, light and airy working place; Implement innovative technologies with regards to environmental control (BMS system); Integration between new technological improvements and the existing building.

Development of didactic tools. The information collected in the previous phases has been transferred and organized into new cognitive didactic tools: "Thematic Maps" on the case studies and "Eh-cmap-00". The "Thematic Maps" refer to the single case studies and represent the contextualization of specific design problems. These "Thematic Maps" have been conceived to foster the knowledge path of the project. Therefore, they are not a mere synthesis of the project, but represent the visualization of a set of concepts answering the focus question about what significant actions of energy efficiency have been implemented in that specific urban context. The use of a common basic structure permits the analysis of similarities among the different case studies. Indeed, the key concept (in this case corresponding to the name of the examined case study) is surrounded by the same linking phrases (e.g., the case study pursues; adopts; promotes). The "Thematic Maps" never develop more than 25 concepts, these averaging out at about 12-15 concepts. In this way, the user will have no difficulty visualizing concepts and starting from these his own cognitive path in relation to his intentionality and prior knowledge. In such a sense, the map is neither simple nor complex. These "Thematic Maps" constitute an important didactic tool used in the course for students to develop their ability to organize concepts in a meaningful way.

A further didactic tool developed in this research study is "Eh-cmap-00" (Energy Efficiency in Historic Heritage Map). The index 00 indicates its updatable nature. In "Eh-cmap-00" all the information deriving from the preparatory phase and from the case studies is gathered and organized. By doing so, "Eh-cmap-00" represents the "knowledge structure" of energy efficiency in historic heritage. Therefore, it does not include universally valid information, but rather a body of shared knowledge, developed through different points of view. The "knowledge structure", in coherence with the cognitive approach, is based on the hierarchical organization of concepts, where higher order concepts include lower order ones. These concepts are linked to each other through the "linking phrases" which express the intention and the direction of the connection among concepts.

At the first level of organization, the map shows the approach to energy efficiency in historic buildings. (Figure 2).
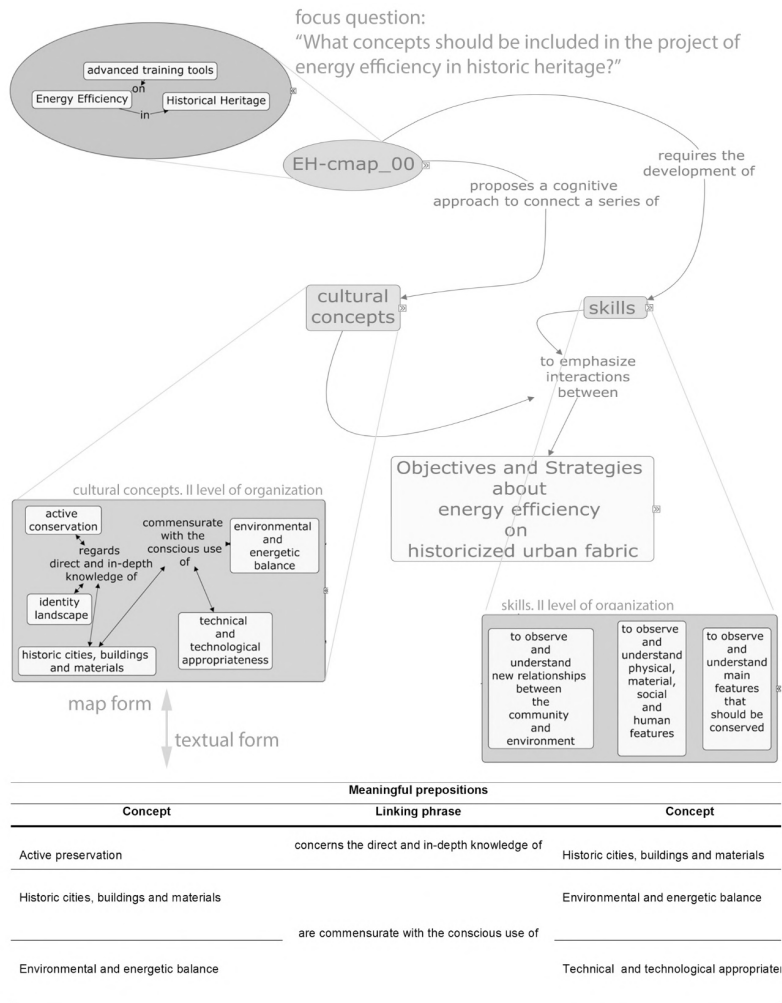
Figure 2. "Eh-cmap-00" first and second level of complexity. At the first level, the map introduces the topic; at the second level, the map explains the ability learners will have to develop and the cultural approach in dealing with the interaction between sustainability and preservation

This issue is linked to some "cultural issues" and, at the same time, to a set of skills the learner is assumed to develop. In this case, the linking phrases explain, on the one hand, the importance of the interdisciplinary approach, and on the other hand, the need to develop the specific skills required to connect the energy efficiency issues with those of the historic preservation. Specifically, these "cultural issues" propose a cognitive framework for the relationships among the different concepts involved in the debate on historic heritage energy efficiency. These "cultural concepts" represent a possible point of view coming from various disciplines. The propositions defined by the organization of concepts and linking phrases clearly show the investigation path complexity. The cognitive process requires the focus question

formulation. "Eh-cmap-00" suggests: "What concepts should be included in the project of energy efficiency in historic heritage?" In relation to our aims, the focus question defines the topic and the field of interest, and calls for the development of the following skills to be observed and understood: new relationships between community and environment; physical, material, social and human features; preservation of the main features. These skills deriving from scientific literature are generic but not trivial, and represent the importance to learn about the connections between material and immaterial factors. Another category of information is the "Eh-cmap-00" technical part, in which the information collected from the case studies data sheets has been transformed (Figure 3).

Figure 3. "Eh-cmap-00" proposes 12 domains of knowledge as general objectives of the project of the energy efficiency in historic heritage.

Through a synthesis and organization process, it has been possible to group similar information, eliminate

the trivial differences, homogenize the terms to explain concepts, transfer the specific technical information to a more general level, define the concepts order and the map hierarchical structure and emphasize the main connections. The result of this operation is an evolution of the concept "General Objectives and Strategies about Energy Efficiency on Historicized Urban Fabrics"

Within this macro concept, there is a series of "concepts" and "linking phrases". Grouped into domains of knowledge, these "concepts" represent a specific application of "cultural issues". The next level of information shows more details about "general objectives and strategies". The map hierarchical organization illustrates some new concepts and reveals specific connections among more detailed concepts (Table 4).

Table 4. Example of propositions related to the domains of knowledge. The table presents the first level of technical information. Within the domains others concepts and relationships can be visualized in order to improve a meaningful discourse

Domains of Knowledge (General Objectives) (main concept)	Material and Immaterial Strategies	
	Linking phrase	Concept
Pursue the widespread environmental quality	through the reduction of	peak energy use
Pursue redaction of use of raw materials	through use of	sustainable building materials
Pursue climate neutrality of the town	through innovative solutions to reach	international standards in energy efficiency
Develop the awareness about the environmental responsibilities	through	communication tools
Develop interactions between natural factors and historic settlements	enhancing the integration of	local geographical condition
Monitoring processes	analyze	energy consumptions in relationship to the profile of uses
Pursue the integration between new technological improvements and the existing building	through	Functional integration of plant engineering systems with construction system
Optimize the use of bioclimatic technologies	through	Passive supply
Reduction of energy losses	through	Minimization of air infiltration
Improve the comfort and interior well-being	taking into account all	local micro climatic factors
Adapt an existing building to a new function	through	Provision for maximum flexibility
Preserve the original integrity of buildings and urban fabric historical	through	accurate restoration of the historical traces

Each domain of knowledge has been associated with 100 open access scientific papers which examine in depth themes pertaining to the specific domains of knowledge, thus giving the opportunity for an orientated detailed study. The complexity level and the type of paper associated with the domain or the

single concept is always variable depending on the learning context. In this way, the domains of knowledge and the concepts are never statically determined and settled; instead, they represent a stimulus to begin a knowledge process. Therefore, the associated papers become useful supporting tools for a guided development of a cognitive path concerning the project of energy efficiency in historic buildings.

The didactic use of "Eh-cmap-00" can be diversified; consequently, together with its development in terms of contents, some guidelines have been prearranged as well.

"Eh-cmap-00" guidelines. When learning to use and construct a concept map, it is important to begin with a domain of knowledge the person constructing the map is very familiar with. "Eh-cmap-00" starts from a focus question that leads users to track the relationship between energy efficiency and historic preservation issues. Moreover, the focus question makes it possible to share the starting point of view.

"Eh-cmap-00" is a tool designed to identify and represent different types of relationships among distinct concepts in a domain, both static and dynamic. Static relationships reduce uncertainty in concepts by connecting them in a proposition, whereas dynamic relationships imply co-variation among concepts. In addition, static relationships among concepts help describe, define, and organize knowledge in a given domain while dynamic relationships between two concepts reflect and emphasize the propagation of change in these concepts. Indeed, a dynamic relationship shows that in a proposition if one concept changes in quantity, quality, or state, another concept changes in the same aspects [12]. In other words, a dynamic relationship reflects the functional interdependency of two or more concepts involved.

"Eh-cmap-00" presents a hierarchical structure to facilitate learning within some different domains. It also proposes a cyclic structure aimed to investigate the relationship between energy efficiency and historic preservation. A cyclic structure represents not just a collection of unrelated propositions, but also a system of interconnected concepts on a given topic. The system representation and the concepts interconnection should appear intellectually more meaningful than a hierarchical representation of the same topic. When using "Eh-cmap-00", it is easier to focus on a specific domain and choose to develop new concepts or to re-label data already provided (Figure 4).
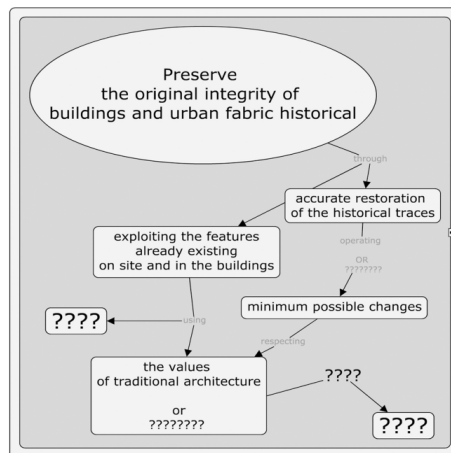
Figure 4. "Eh-cmap-00" preliminary use. Learners can operate in a specific domain of knowledge and manipulate it.

At the same time, it is preferable a cyclic to a hierarchical representation of the same topic. The cyclic structure produces more dynamic propositions than any hierarchy form (Figure 5).
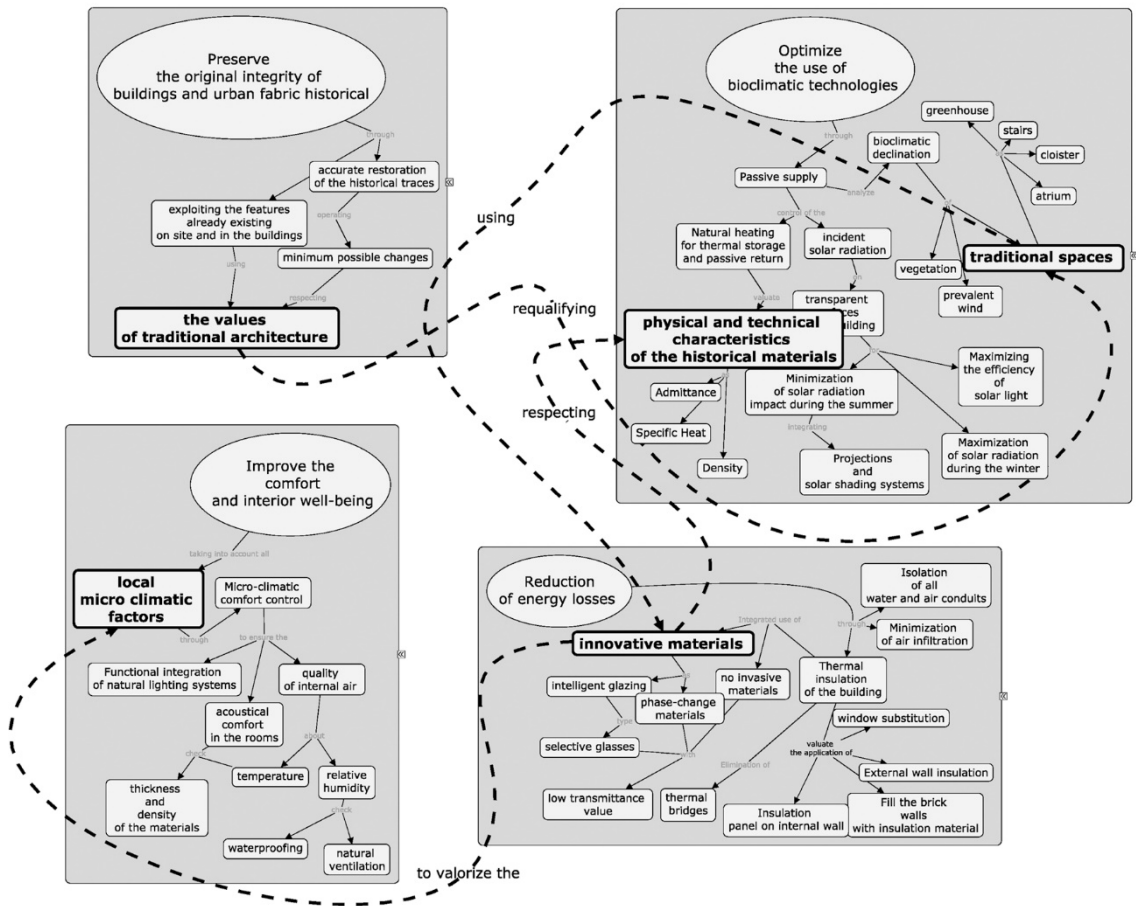
Figure 5. "Eh-cmap-00" preliminary use. Learners can connect several concepts derived from various domains of knowledge and propose an original interdisciplinary meaningful discourse.

Method and tools testing for trainers. Twenty trainers of various disciplinary extraction have taken part in the course. The course main purpose has been to collect reflections on the applicability of the meaningful learning method in the field of historic heritage energy efficiency as well as to discuss "Eh-cmap-00" tool functionality as an important support to the implementation of the meaningful learning activities. Participants have been so distributed: seven researchers and professors experienced in architecture and preservation technology; five professional architects operating in the energy efficiency field for public authorities and private companies; three professors working in the social science sphere

and particularly expert in historic heritage preservation; three economists and an engineer specialized in Economics and Management of Energy, a geographer expert in territorial planning. They have represented the interests of five European countries.

Method and tools testing for students. Twenty students have been selected to participate in this didactic experience. They have been so grouped: ten architecture students (of which three undergraduate ad seven postgraduate); seven civil engineering post-graduate students and three social science postgraduate students, qualified for historic heritage preservation. Prior knowledge on the topic of historic buildings energy efficiency was a necessary prerequisite for the students' participation. The course main purpose has been to develop the ability to manage the complexity of the topic at issue. For this purpose, four exercises have been organized so that each exercise could develop a specific phase of the knowledge path coherently with the meaningful learning activities. Then, the structure of the exercises carried out has been presented, highlighting their specific objectives, the didactic method and the tools used, and the expected results.

Table 5 provides a synoptic overview of the activities.

Table 5. Synopsis of educational activities organized in the course for students

	Exercise	Objective	Didactic tools	Focus question	Procedure
1	**Preliminary construction of prior knowledge**	To assess the level of prior knowledge	List of concepts	What concepts should be included in the design for the energy retrofit of historic buildings?	1_List coherent concepts in response to the focus question (60 minutes) 2_Brainstorming
2	**Didactic use of "Eh-cmap-00"**	To build prior knowledge on Energy Efficiency in Historic Heritage	"Eh-cmap-00"; Cmap software		1_ Read "Eh-cmap-00" and select 15-25 concepts you know; 2_Rank in order of complexity (from the most general to the most detailed concepts; 3_Choose explicit Linking words to relate concepts; 4_Continue building concept hierarchy ; 5_Search for possible cross-links 6_Brainstorming
3	**Didactic use of the Case Studies**	To articulate knowledge on Energy Efficiency in Historic Heritage	Case studies both in textual form and map form; Cmap software	What concepts and relationships can you articulate in the selected case study?	1_Compare the textual and the map form of the case studies; 2_Point out the concepts and relationships you consider more relevant to the existing map; 3_Search for more information on the textual form ; 4_Articulate the map with the new information; 5_Search for possible cross-links 6_Brainstorming

| 4 | **Mapping scientific papers** | To deepen knowledge on Energy Efficiency in Historic Heritage | Scientific Paper; "Eh-cmap-00"; Cmap software; the Internet | Proposed by participants | 1_ Identify relevant concepts from scientific papers; 2_Elaborate the focus question; 3_Connect the new concepts with those proposed by "Eh-cmap-00"; 4_Talk about your choices with your colleagues |

3 Research analysis

This chapter presents the main results used to elaborate the answers to the research questions proposed in this paper.

The data analysed are, substantially, behavioural data concerning the participants of the two intensive courses, for trainers and students. Specifically, the information collected and converted into results refers to the interaction among participants, cognitive tools and the procedure elaborated in this experience. Therefore, the Table 6 shows the main results illustrating a framework of organized indexes. These indexes are a valid tool to manage the cognitive path for the construction of a meaningful discourse on the historic building energy efficiency.

Table 6. Cognitive process qualitative indexes organized into assessment criteria and preliminary definition of evaluation indexes

1	**Quality of hierarchical structure**	2	**Quality of meaningful discourse**	3	**Quality of external links**
1.1	Number of concepts	2.1	Clarity of the focus question	3.1	Coherence with external links
1.2	Number of cross-links	2.2	Articulation of sentences	3.2	Explanatory notes
1.3	Number of nidifications	2.3	Logic of discourse	3.3	References to support the study

Indexes definition
Number of concepts: Ability to gather information
Number of cross-links: Ability to build dynamic connections among concepts
Number of nidifications: Ability to easily switch from simple to complex forms of knowledge representation
Clarity of the focus question: Ability to clearly define a problem
Articulation of sentences: Ability to articulate a concept through a logical sequence of more and more detailed information
Logic of discourse: Ability to competently present a topic
Coherence with external links: Ability to enhance interactive learning
Explanatory notes: Ability to provide information to facilitate knowledge understanding and sharing
References to support the study: Ability to select relevant documents and connect them with the concepts

Through such indexes, the participants have pointed out the resistance of the rote learning in the context of the complex design training and traced a path towards a meaningful learning. The framework of organized indexes presents three fundamental features: firstly, it is based on an adaptable hierarchical structure; secondly, each index refers to a literature definition; thirdly, the indexes can be associated to different forms of assessment, qualitative or quantitative, in relation to the scope of the research.

It is useful to explain that in this context, where both trainers and students had no deep knowledge of the cognitive approach and "Cmap tools" software, this study has opted for a qualitative use of the indexes in order to assess the efficiency and efficacy of the meaningful mapping approach for complex design training, which is the relevant topic of this paper. So, at the end of this chapter it has been introduced a comparative assessment applied to one exercise carried out by students (exercise n.4).

Before introducing the assessment, it has been considered worthwhile providing the indexes traceability starting from a more detailed reading of the research analysis developed within the intensive courses.

During the course for trainers, "Eh-cmap-00" has been used in order to understand how a group of experts could relate with the inputs offered by the cognitive tool.

Figure 6 clearly shows the tool manual use and the mapping technique employed by a shared working table.
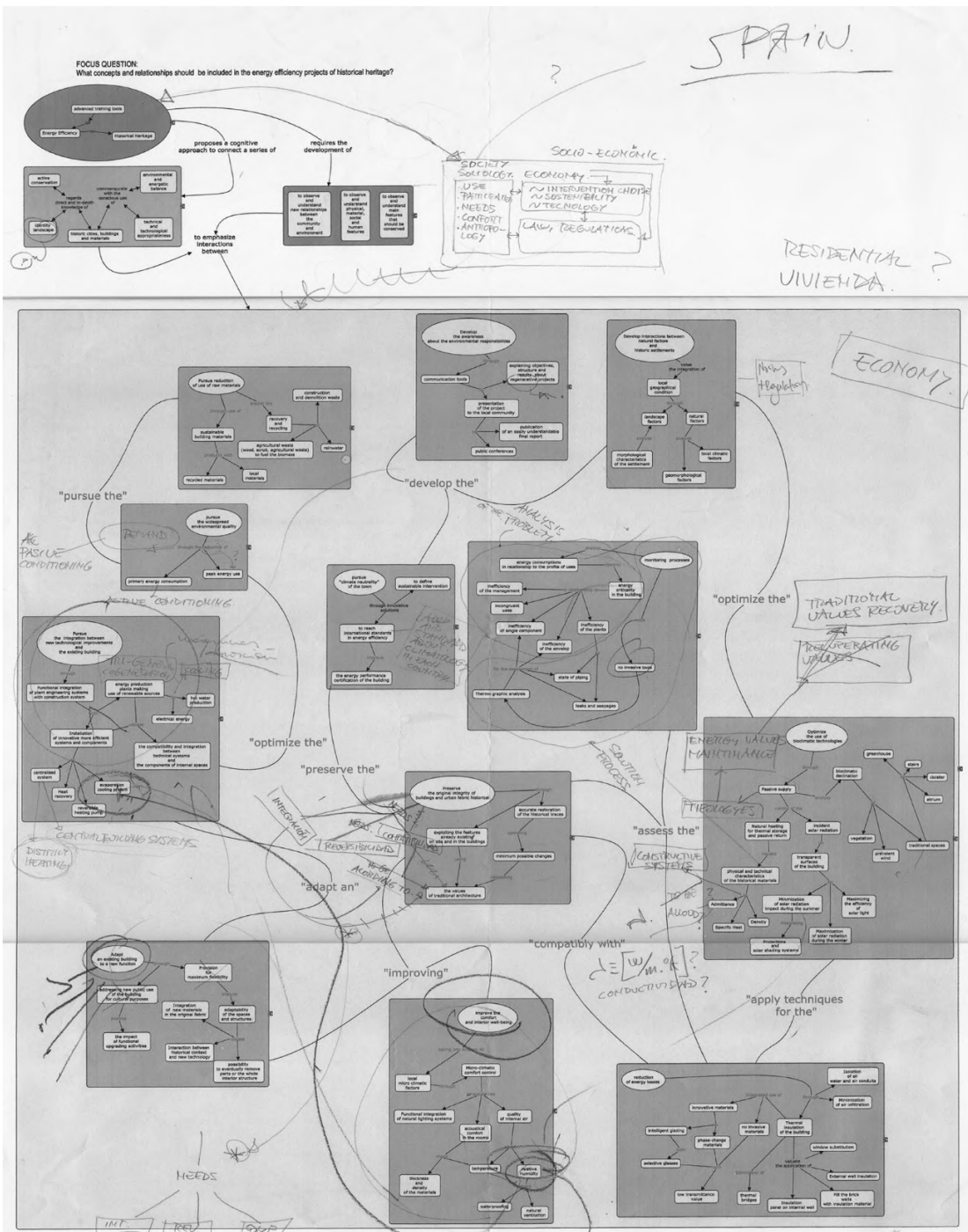
Figure 6. Example of "Eh-cmap-00" adaptation made by a group of experts during the intensive course for the teaching staff.

The most important outcome to highlight is the use of "Eh-cmap-00" as a basic tool to present points of view of different disciplinary extraction and to open interesting discussions pertinent to this specific topic (Figure 7).

Figure 7. First intensive course: collaborative and conversational activity among teaching staff.

In particular, six main actions have been identified as output of the application of the meaningful learning activities with the support of "Eh-cmap-00": Clarification of concepts; Introduction of new concepts; Articulation of old concepts; New propositions with the same concepts; Introduction of new connections; Introduction of new domains of knowledge. The table 7 shows the diversified use of "Eh-cmap-00" to propose and elaborate one's own stance with regard to historic buildings energy efficiency in an interdisciplinary context. Therefore, the manipulation illustrated into table 7 suggests how the design teachers relate and react to the new cognitive-oriented learning affordance.

Table 7. Cognitive actions developed by participants with the support of "Eh-cmap-00" in the intensive course for the teaching staff

Groups composition	Clarification of concepts	Introduction of new concepts	Articulation of old concepts	New propositions with the same concepts	Introduction of new connections	Introduction of new domains of knowledge
Group A n.1 expert in energy systems n.3 experts in energy management	●	●		●		●
Group B n.4 experts in architectural technology and environmental design		●	●	●		●
Group C n.3 experts in energy systems n.1 expert in informatics systems	●		●			
Group D n.2 experts in architectural technology n.2 experts in historic heritage preservation					●	
Group E n.3 experts in architectural technology and preservation n.1expert in geography	●			●	●	

For example, Group A interacts with "Eh-cmap-00" in a critical way, noticing the lack in "Eh-cmap-00" of financial measures related to the issues of historic buildings energy efficiency. In a similar way, Group B proposes the introduction of a specific topic related to the energy modelling, underling that such an issue is significant for the listed buildings. In both cases, the groups introduce new domains of knowledge in order to visualize and communicate their prior knowledge and expertises.

Other indexes represented in table 7 show how the experts have manipulated the "Eh-cmap-00" hierarchical structure, providing significant insights into the existing issue or introducing new paths of investigation (i.e., Introduction of new concepts; Articulation of old concepts) It is interesting to emphasise that, as figure 6 points out, the manipulations proposed by the participants involve the whole "Eh-cmap-00", crossing different domains of knowledge. This is very important since it means that the memory load, generally high in the traditional learning approach, through the use of EH-cmap-00 tends to

zero. Moreover, the sharing of a structured knowledge has allowed the participants to visualize the different cultural approaches on the given topic.

In fact, all the implemented actions have shown that "Eh-cmap-00" has been able to stimulate a sharing attitude aimed to build a meaningful discourse on the topic of historic buildings energy efficiency. Indeed, in this interdisciplinary context these actions have led to the sharing of some definitions (e.g., preservation, re-use, landscape, technology etc.). Moreover, most of the discussion has been especially about the belonging of some concepts to a determined domain or the presence/absence of some linking phrases (note that "Eh-cmap-00" never proposes the repetition of a concept). It is interesting to emphasize that, at the beginning of the discussion, the positioning in a single domain has been considered a limitation of "Eh-cmap-00" effectiveness in giving useful information. In a first moment, users skilled in their own fields but inexperienced in the cognitive approach have expressed their doubts about "Eh-cmap-00" as not able to represent their own conceptual point of view. In a second moment, through the implementation of the meaningful learning activities, all participants have understood the important role of "Eh-cmap-00" in suggesting interferences which have later triggered lively interdisciplinary debates.

The presence of a guiding map has made it possible to communicate innovative interpretations of concepts and to visualize both the interconnections and the distances between different disciplinary methodological approaches. Above all, it has been possible to begin the creation of a common vocabulary, this being an essential condition, often denied, in interdisciplinary and group works.

At the same time, the intensive course for students has permitted to examine how the participants could develop ideas and concepts on historic building energy efficiency.

First of all, students with exercise n.1 have been engaged to communicate their prior knowledge through the elaboration of a simple list of concepts. Therefore, each student has produced a list of concepts (Table 8) to describe his own interests on energy efficiency and preservation.

Table 8. List of concepts proposed by participants

Focus question:	**What concepts should be included in the design for energy retrofit in historic buildings?** (Time given for drawing up the list: 60 minutes)
Students	**Concepts list**
S01	bioclimatic devices; passive devices; artificial devices; devices development; energy efficiency control
S02	devices for existing buildings; climate strengths; climate weaknesses; bioclimatic approach; physical dimension
S03	green roof; vertical gardens; solar heating; energy efficiency class; hybrid ventilation
S04	renovation; architectural design; bio-climate; history; materials; nature; zero impact energy; analysis; technology; comfort
S05	water system; materials; technologies; low waste of CO_2; envelope requalification; using renewable energy; comfort
S06	preservation; restoration; authenticity; investments
S07	city infrastructures; green energy; smart cities; new technologies for new needs; interaction; economy services; strategic planning; mobility; technology resilience; agriculture innovation; temporary architecture
S08	materials; urban conservation; passive systems; innovative materials; architecture for emergency; recycling; blue economy; technologies; smart cities; preservation; slow mobility
S09	historic buildings preservation; documents; ideal condition of conservation;

	administrative history of institutes; ideal tools; ideal conditions of energy efficiency; interest in historic archives
S10*	Preservation (* Note: S10 stated he did not understand the exercise)
S11	energy saving; water management; informatics technique; physical; service conditions; wind and sun benefits; domotics; maintenance historic heritage
S12	thermal comfort; authenticity; sustainable intervention; energy saving; air quality; environmental quality; recyclable materials
S13	heritage preservation; landscape memory; non-intensive construction; history; thermal comfort; energy saving; air quality; natural lighting; architecture
S14	envelope materials; requalification; traditional technologies; low-grade waste of energy; comfort; nearly zero buildings; optimization
S15	building envelope; materials features; using natural elements; passive systems; authenticity; preservation; comfort; landscape; building memory; sustainable memory; rehabilitation; intervention; heat factors; energy saving; architecture
S16	building study; thermal comfort; acoustic comfort; authenticity; sustainability; interaction; materials reuse; indoor comfort; natural lighting; natural ventilation; innovative materials; renewable energy; reducing energy consumption; minimal change; hot water
S17	energy efficiency; passive methods; low energy comfort; materials; historic heritage; traditional technologies; green infrastructures
S18	preservation; conservation; sustainability; technological architecture; feasibility; efficiency; implementation; materials; construction techniques; practice; construction site
S19	heritage; history; conservation; sustainability; restoration; energy efficiency; maintenance costs; study; differences; new technologies for new functions; materials; construction techniques; comparison with the pre-existing buildings
S20	thermal comfort; welfare; air quality; intervention; sustainable construction; architecture; innovative materials; lighting; natural ventilation; energy efficiency; authenticity; solar radiation

The list of concepts represents the starting point to activate the collaborative work ensuring all students' participation. The collaborative work has started from an initial discussion in order to give sense and value to the concepts proposed. In particular, the elaboration of the list of concepts is intended to stimulate the next step with students being called to interact with "Eh-cmap-00" which is quite a complex tool. Hence, each student has had the possibility to find at least one of the concepts proposed in his list within "Eh-cmap-00". In this way, each student has found a familiar starting point to interact with the cognitive tool, whether or not the proposed concept was located in a network of already known connections.

Indeed, in both cases "Eh-cmap-00" has been able to encourage an investigation path, as underlined by the results of exercise n.2. In this context, the result obtained with the support of the new shared cognitive scenario is inferred from the participants' easiness in elaborating conceptual mappings and specific thematic connections pertinent to the project of energy efficiency in historic buildings.
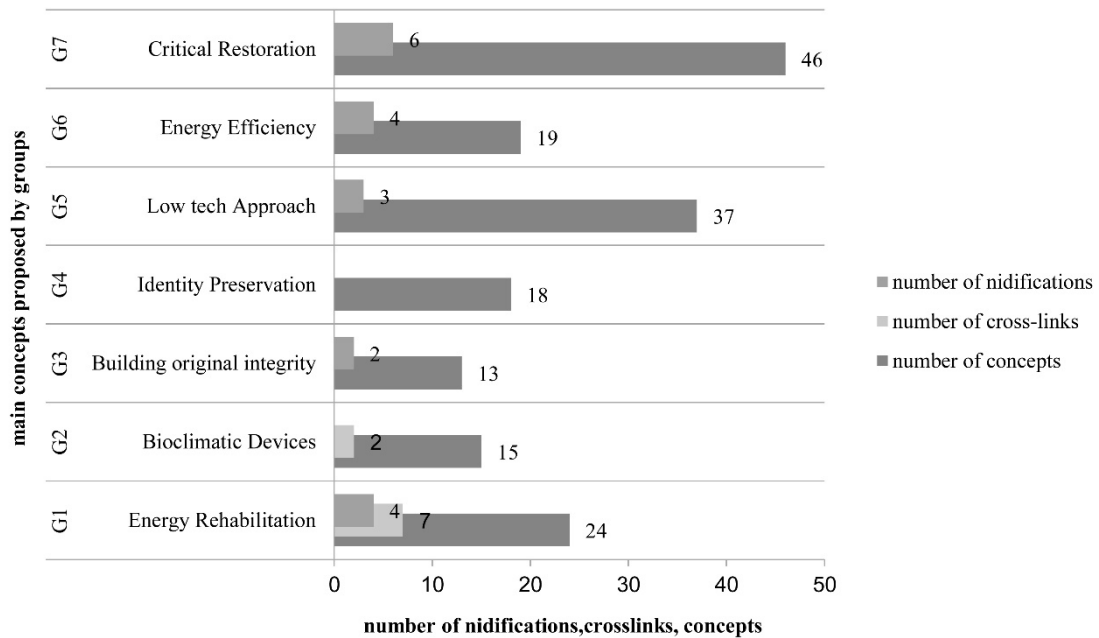
Figure 8. Assessment of the meaningful concepts critical elaboration

For example, examining figure 8, two significant considerations emerge. On the one hand, the figure reveals how all groups have identified a specific concept to start a personal investigation. On the other hand, the c-map functionalities, especially the possibility of analyzing the connections structure and sequence, have pointed out relevant criticalities come out while developing a meaningful discourse on the topic proposed. As mentioned in chapter 2.1, the c-map functionalities are not only a graphical tool. The nidifications, the cross-linking phrases and the concepts represent important elements to build a meaningful discourse. Figure 8 shows how only G1 has appropriately used the c-map functionalities, proposing a cognitive hierarchical organization of the concepts concerning the energy rehabilitation issue.

Figure 9 shows the map elaborated on the energy rehabilitation concept which is related to four domains: Improving the interior well-being; Original integrity; Energy criticality in the building; New Technological improvement. Such an articulation reflects the group reasoned choice, thus representing an original and critical information modelling on the theme. Moreover, regardless of the different manner, the map proposes a specific reasoning for each domain. In any case, it seems more interesting the group effort to build transversal relationships among the domains, this being typical of the complex design.
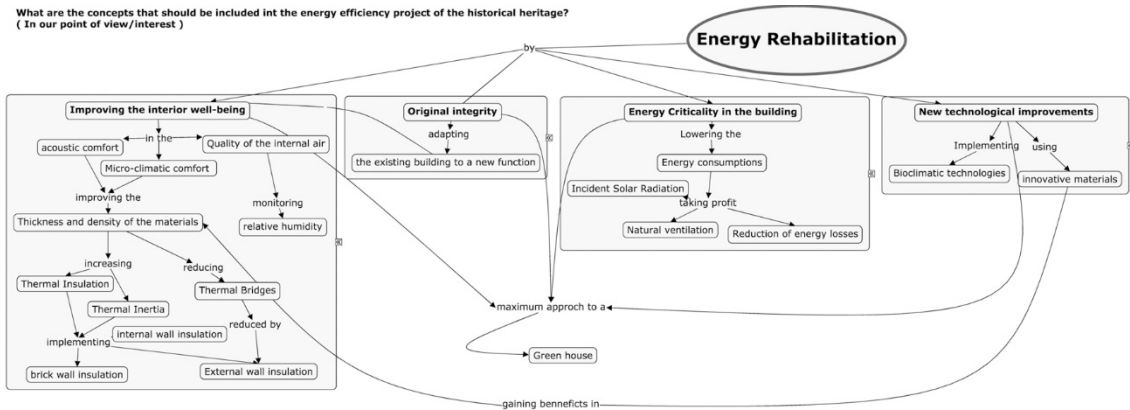
Figure 9. Map elaborated by a work group to point out the main concepts about the project of the energy efficiency in historic heritage with the support of "Eh-cmap-00".

The map clearly presents a strong naivety, which is partly due to the inexperience in the use of the software. Nevertheless, some indexes to manage the complexity of the meaningful discourse have emerged and later they been used as subject matter for discussion to improve and articulate the discourse on the topic selected. (Figure 10)

Figure 10. Second intensive course: collaborative and conversational activity among students.

The skills to articulate a meaningful discourse are enhanced with exercise n.3

The outcomes of exercise 03 concern the articulation of the participants' prior knowledge. Students have produced new maps as articulation of the case studies maps. With the support of the case studies, both in textual and map form, they have been able to identify the main topics of the case analysed. The comparative evaluation of maps has stressed deeply different attitudes of critical reading among the participants (Figure 11).
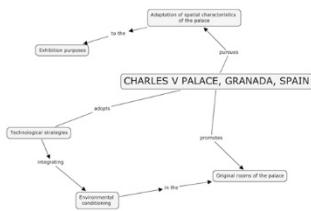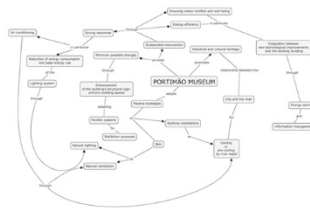

a: basic thematic map on
Charles V Palace, Granada, Spain

b: basic thematic map on
Portimão Museum, Lisbona, Portugal
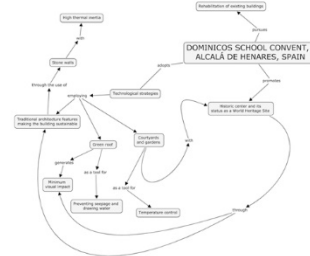
c: basic thematic map on
Dominicos School Convent, Alcala De Henarse, spain
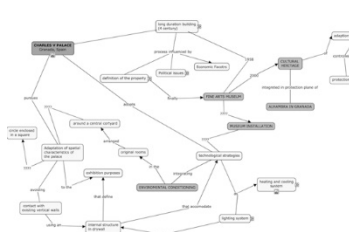
a: thematic map elaborated by G_04

b: basic thematic elaborated by G_06
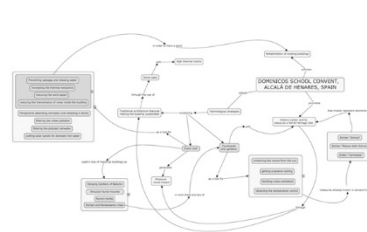
c: basic thematic map elaborated by G_07

Figure 11. a) The map shows a great number of concepts but it does not propose a logical sequence of propositions since many linking phrases are unresolved. b) The map shows a good articulation of concepts even if they lack a clear organisation. C) The map shows a good articulation and a clear hierarchical structure highlighting some significant cross-links as indexes of complex reasoning.

Therefore, comparing maps has made it possible to infer some quantitative indexes which effectively indicate the students' critical reading (Table 9).

Table 9. Indexes of "Thematic Maps" customization process

Group	Case study	Strengths	Weaknesses	New concepts	Presence of cross-links
01	1878 Hostel Faro, Faro, Portugal	Very good articulation of concepts; Good hierarchical structure; Proposed interesting connections	Absence of nidifications	32	yes
02	Ghella Offices, Rome, Italy	Quite good articulation of concepts	Unsatisfactory hierarchical structure; Absence of nidifications	24	yes
03	Cineteatro Louletano Loulé, Algarve, Portugal	Quite good articulation of concepts	Nidifications as folders for concepts not as domains of knowledge; Proposed not relevant concessions	18	yes
04	Charles V Palace, Granada, Spain	Collected a relevant number of concepts	Some connections are not identified with linking phrases	17	no
05	Villa Torlonia Theatre, Rome, Italy			24	no
06	Portimão Museum, Portimão, Portugal	Good articulation of concepts	Complicated hierarchical structure	23	yes
07	Dominicos School Convent, Alcalá De Henares, Spain	Good hierarchical structure	Nidifications as folders for concepts not as domains of knowledge	17	yes

It is worthwhile underlining that the effective capacity to propose a significant discourse always refers to the reading of a sequence of propositions. During the course, the discourse significance has been directly assessed through groups of students presenting their maps.

In addition, other indexes have emerged from exercise n.4, these also being strongly connected with the

software functionalities.

Exercise 4 specifically concerns the elaboration of a focus question as first step to integrate the prior knowledge with new relevant information. First, students have selected a specific scientific paper by pulling it out from those previously collected in relation to the "Eh-cmap-00" domain of knowledge. Then, students have produced seven maps dealing with new technical and non-technical issues about energy efficiency in historic buildings.

Finally, the papers chosen by groups and the connections with the domains of knowledge of "Eh-cmap-00" have been shown pointing out the focus question proposed by each group as index of meaningful reading (Table 10).

Table 10. Relation between the scientific paper selected by participants, the focus question proposed and "Eh-cmap-00" knowledge domain investigated

Group	Scientific paper analyzed by participants	Focus Question proposed by participants	"Eh_Cmap-00" knowledge domain investigated
01	Application of latent heat thermal energy storage in buildings: State-of-the-art and outlook [60]	How to store thermal energy?	Reduction of energy losses
02	Energy efficiency of windows in historic buildings [14]	not declared	Use of bioclimatic technologies
03	Cultural heritage and sustainable development in SUIT [15]	How to investigate urban historical areas sustainability?	Cultural issues
04	Energy rehabilitation studies of a large group of historic buildings: a case study [51]	How to rehabilitate energy performance in historic buildings?	Original integrity of buildings and historic urban fabric
05	Energy efficiency and renewable solar energy integration in heritage historic buildings [29]	How to integrate solar energy in heritage historic building?	Integrations between new technological improvements and the existing buildings
06	Definition of a new planning process function [59]	What planning processes are necessary to rehabilitate historic buildings?	From existing to new buildings
07	Beyond Restoration. Valorization of a Public Monumental Heritage Asset [52]	not declared	Cultural issues

As shown by Figure 12, the focus question on" How to store Thermal Energy" is directly connected with a specific issue as the role of "Phase Change Materials". An additional table on a phase change materials properties has also been integrated into the map as external link in order to increase the knowledge of this topic.
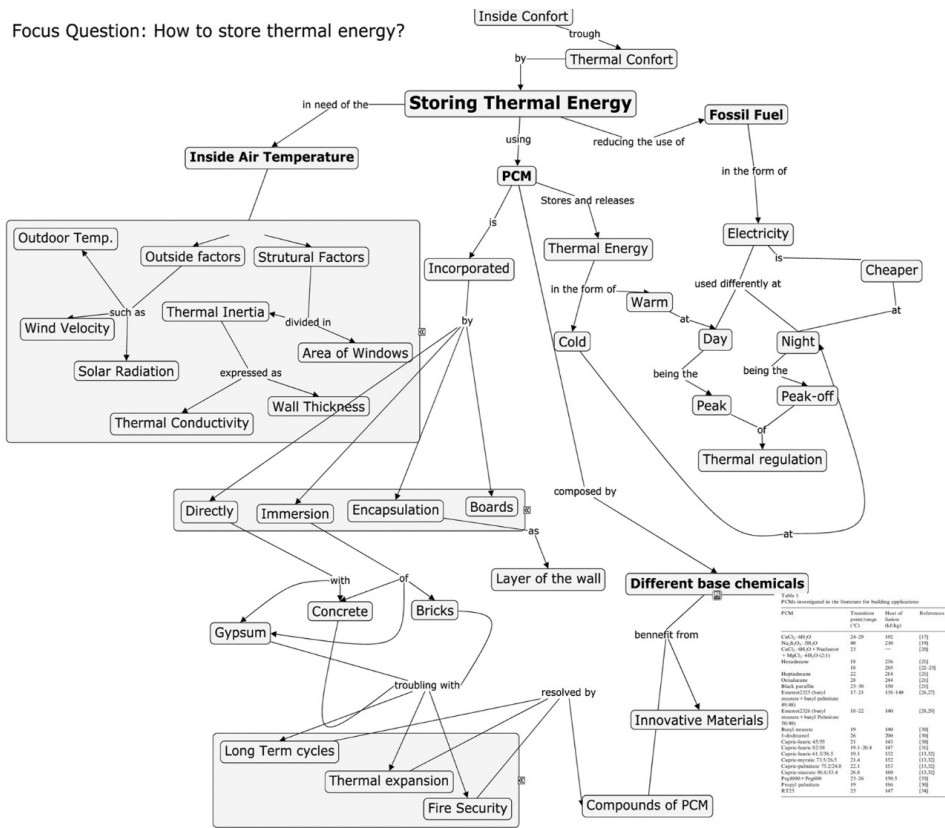
Figure 12. Map elaborated by a work group from the reading of scientific papers on the topic of thermal storage.

In other circumstances, students have used comments and notes (other functionalities of c-map) to give more information to the concepts elaborated.

The possibilities of integrating external links (i.e. text, image, table) to the concepts become particularly significant to develop the ability to know the difference between relevant and trial information. In this experience, these features of c-map functionalities have been considered secondary since they require a deeper knowledge of the software.

In conclusion, from the research analysis carried out, a considerable number of indexes have been collected and organized in order to highlight the qualities of the cognitive approach adopted. Therefore, such a framework of organized indexes has turned out to be a supporting tool able to provide a preliminary assessment.

Figure 13 illustrates a simulation of a synthetic comparative evaluation between "Thematic Maps" developed during exercise n.4 considering the assessment criteria overall. The comparison is based on a normalized metric weight system in order to put together indexes of different nature. The metric weight system goes from 0 to 1 and represents the assessment rate achieved (ar). Depending on the needs, the comparison can be based on more specific indexes and well-structured assessment classes.

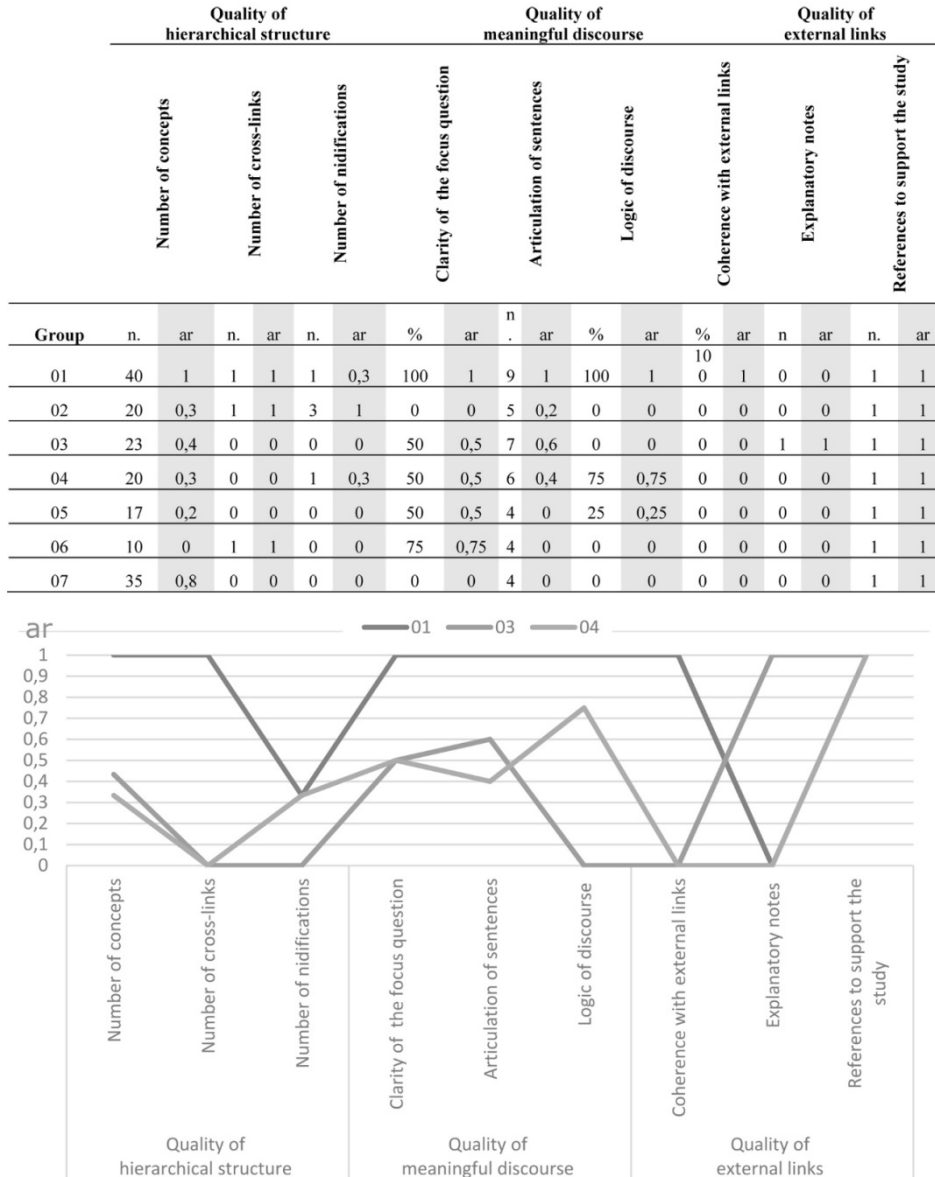| | Quality of hierarchical structure | | | | | | Quality of meaningful discourse | | | | | | Quality of external links | | | | | |
| | Number of concepts | | Number of cross-links | | Number of nidifications | | Clarity of the focus question | | Articulation of sentences | | Logic of discourse | | Coherence with external links | | Explanatory notes | | References to support the study | |
Group	n.	ar	n.	ar	n.	ar	%	ar	n.	ar	%	ar	%	ar	n	ar	n.	ar
01	40	1	1	1	1	0,3	100	1	9	1	100	1	100	1	0	0	1	1
02	20	0,3	1	1	3	1	0	0	5	0,2	0	0	0	0	0	0	1	1
03	23	0,4	0	0	0	0	50	0,5	7	0,6	0	0	0	0	1	1	1	1
04	20	0,3	0	0	1	0,3	50	0,5	6	0,4	75	0,75	0	0	0	0	1	1
05	17	0,2	0	0	0	0	50	0,5	4	0	25	0,25	0	0	0	0	1	1
06	10	0	1	1	0	0	75	0,75	4	0	0	0	0	0	0	0	1	1
07	35	0,8	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	1

Figure 13. The diagram compares three different students' maps highlighting strengths and weaknesses of the knowledge path.

4 Conclusion and Recommendation

The experiment performed in this study has tested a new cognitive approach for the training in the complex design of energy efficiency in historic buildings. First, this study has explored the procedure of integration of the five meaningful learning activities with the "Cmap Tools" software main functions within a didactic structure specifically devoted to investigating the complex interactions between sustainability and preservation. Then, the didactic tools elaborated to develop the abilities necessary to manage the complex design have been tested.

In such a way, the research work carried out have constituted an interesting contribution towards filling the following deficiencies:

- the incompleteness of a systematic, theoretical and operational study referring to the problems of preservation and sustainability [10]
- the lack of educational programmes dedicated to interdisciplinary training capable of facilitating learning and information transfer from different disciplinary spheres [41]
- the insufficiency of tools able to facilitate orientation, comprehension and modelling of complex themes, whose handling is necessary to the construction of integrated project logics [26].

Obviously, the path to fill these gaps is long and difficult. This study should be intended as the first step of this path. In this first step, the significant connections between disciplinary boundaries (buildings energy efficiency, cognitive psychology and pedagogy) have been the core of the present investigation in order to develop an efficient methodological and instrumental apparatus for the complex design of energy efficiency in historic buildings. Consistent with such a purpose, the following chapters provide answers to the research questions formulated before and lay particular emphasis on the most important implications between the key concepts of the cognitive approach and the methodological and instrumental apparatus.

At the end, from the experiences carried out, the elements of major interest for the development of further research are detected.

4.1 Conclusions

The experiments outcomes support the hypothesis of systematizing the meaningful learning activities with computer applications dedicated to the elaboration of cognitive maps. The products developed, such as "Eh-cmap-00", the "Thematic Maps" of the case studies and the guided exercises procedure represent a training device helpful to increase the capacity to manage complex information and to bring out significant interactions between sustainability and preservation. The experiments outcomes of the course for trainers and students permit to give some preliminary answers to the research questions proposed at the beginning of the present paper.

In relation to the research question (1), the use of a software based cognitive thinking tool has proved to be able to generate a cognitive path better than a traditional approach. Indeed, the traditional approach, however based on advanced and dynamic informative tools, hardly supports the synchronization of the participants' views. Instead, in the cognitive process proposed here, both trainers and students have succeeded in communicating their cultural stance on the theme of energy efficiency in historic buildings,

keeping it visible and flexible with reference to the evolution of the debate in progress. Although in the proposed exercises the use of this approach has not led to the elaboration of specific designing solutions to energy efficiency in historic buildings, it has clarified the modalities to contrast the forms of mechanical learning involving both trainers and students. By exactly revealing these learning mechanisms, this approach support can be considered a superior process since it stimulates new ideas and interconnections among various concepts referring to the project of energy efficiency in historic buildings.

As far as the research question (2) is concerned, the experiments conducted have highlighted a set of indexes capable of clarifying the quality of the students learning process and of developing specific cognitive skills. Through a sequence of exercises, students have had an interactive confrontation, understanding their own mechanical attitudes. On the other hand, the developed procedure has encouraged a gradual process of familiarization with the themes of energy efficiency in historic buildings starting from the simple list of concepts elaborated individually by every single student to the collaborative construction of more complex maps able to explain, share and examine in depth a specific view on the given topic.

With regard to the research question (3), the described experiences have brought to light the affordances of the elaborated tools, in particular those of "Eh-cmap-00". As known, the affordance defines the physical quality of an object suggesting the appropriate actions of manipulation to human beings. As inferred from the outcomes presented above, the affordances correspond to a series of actions developed spontaneously by the participants and representing the answer to how the design teachers/trainers relate and react to the new cognitive-oriented learning affordances. Later, the actions of clarification of concepts, introduction of new concepts, articulation of old concepts, new propositions with the same concepts, introduction of new connections, introduction of new domains of knowledge have been reorganized as specific elements of the didactic programme in the course for students developing, as already underlined, a well-structured set of indexes to assess the ability to manage complexity in the project of energy efficiency in historic buildings.

To conclude, in response to the question whether the approach can be effective and efficient, the outcomes emphasize:

- the modalities of activating the collaborative work, these being useful to find out significant issues in interdisciplinary scenarios characterized by a high complexity of design;
- the process of prior knowledge involvement and its active role in developing technical skills, correctness of speech and design creativity;
- the configuration of a well-organized and structured knowledge-building capable of giving sense and value to the involved concepts and their relationships;
- the development of a problem-based learning path which has to be articulated and scrutinized with particular guiding tools support;
- the map functionality as an assessment tool, both individual and comparative, of the developed cognitive path quality.

4.2 Implications

In this chapter, there is an in-depth analysis of the implications between the approach and the tools adopted in the field of education in the project of energy efficiency in historic buildings and the key elements of the cognitive approach. The main aim of this discussion is to strengthen the prearranged

methodological and instrumental apparatus and to provide a documented support to the answers given to the research questions. Therefore, the results obtained will be discussed in detail in relation to the five key-concepts of the cognitive approach already investigated by cognitive science and included here: prior knowledge; knowledge structure; Problem-Based Learning; instructional technique.

Collaborative work activation. Roschelle and Teasley [45] have stressed the importance of group work. Hiltz et al [18], Hobaught [19], Taha and Caldwell [49] have demonstrated with their studies that assigning students to groups and giving them a task is not sufficient to have students actually engaged in a significant collaborative work. In order to activate an effective collaborative work, it is necessary to fulfil some specific surrounding conditions.

Indeed, the peculiarity of the approach adopted precisely lies in the creation of such specific surrounding conditions described by Norman and Schmidt [33] as follows:

- learning in the context of meaningful problems;
- actively constructing mental models which help understand these problems, using prior knowledge;
- learning by sharing cognitions about these problems with peers;
- developing self-directed learning skills.

In this study, the surrounding conditions have been activated from the first exercises, but only with "Eh-cmap-00" support, these conditions can organize themselves within the training process since:

- "Eh-cmap-00" summarizes a diversified set of concepts concerning historic buildings energy efficiency. Such concepts derive from real cases and allow participants to confront with concrete and significant problems;
- "Eh-cmap-00" is endowed with an enlargeable and easily adaptable structure which has made the study of significant problems possible through the construction of different mental models to describe a design problem which is generally at the core of the designer's activity;
- "Eh-cmap-00" facilitates the discussion and the reflection on specific concepts fostering a shareable common language, trans-disciplinary exchanges and collaborations are founded on;
- "Eh-cmap-00" permits a differentiated use moving from simple to more complex visualizations depending on the user' s knowledge.

Akkerman et al.[2] and Beers et al.[7] have underlined that group work rests on the sharing of a focus question and common objectives. Answering a focus question can imply distinct levels of complexity and, in agreement with Ohtsubo [38], the more complex the work is, the more efficient and significant the group work is likely to turn out. The approach adopted in this study is grounded in the focus questions construction. In the course for trainers, asking the same question has determined the opening of a collective discussion integrating different points of view within a common reference framework. In the course for students, the didactic programme has been structured around exercises of distinct levels of complexity producing continuous information exchanges inside the single group and among more groups.

The process effectiveness in contrasting mechanical learning attitudes is especially clear in the diversity of concepts suggested by the groups, this being referred both to trainers' proposals of integration into "Eh-cmap-00" and to students' wide variety of concepts. Sharing common objectives has promoted a dynamic information exchange and the mapping technique has permitted these dynamics coding.

Prior knowledge involvement. Schmidt et al. [48] have pointed out the importance to start the formative activity from prior knowledge. Prior knowledge is measured on the user's level. Even an inexperienced user can visualize his own prior knowledge which so becomes the basis to direct and understand the newly acquired information.

In this study, prior knowledge is first activated through a list aimed to start a discussion on the sense and value concepts should be given. This list shows that the concepts are often used improperly, or with different disciplinary meaning. Furthermore, the list underlines how participants are inclined to insert their own concepts, even if the connection between the listed concepts and the main topic does not appear clear (e.g., urban agriculture).

In such a context, "Eh-cmap-00" acts as a valuable guiding tool for the building of an efficient prior knowledge model. It is worthwhile highlighting that, thanks to the use of "Eh-cmap-00", it has been possible to activate both the capacity to organize hierarchically the listed concepts and the participants' dormant memory bringing to light forgotten concepts and interactions.

The individual lists, the shared domains of knowledge and the issues investigated by each group outline the different levels of complexity of prior knowledge representation which, in agreement with Chi et al. [9] and Pressley et al. [42], generates stimulating debates.

Organized and structured knowledge building. Paas, Renkl and Sweller [40] have emphasized that, particularly for novice learners, the lack of a personal strategy or approach to integrate new information with prior knowledge produces a memory workload potentially damaging to learning. In line with this point of view, both "Eh-cmap-00" and the "Thematic Maps" fulfil the function of supporting knowledge organization since defining a knowledge framework entails learners gradually moving from the simplest to the most complex, first facing easy understanding problems and then issues for experts.

The adopted approach main purpose has been to illustrate the tool capacity to combine with a significant study investigating the possible interactions between sustainability and preservation through a sequence of exercises calling for the activation of some specific abilities highlighted by the cognitive mapping technique such as:

- identifying a concept as expression of a design problem;
- subordinating to the main concept a series of concepts helpful to contextualize a problem;
- investigating complex relationships by associating concepts, even non-sequential, able to articulate the detected problem;
- gathering useful information through the visualization from simpler to more complex maps, as convincing evidence of the ability to manage significant discourses pertinent to the defined topic.

The results obtained have displayed the participants' critical reasoning quality revealing some passive and mechanical attitudes.

Design problem focusing. This study approach to tackle the topic of the complex design of energy efficiency in historic buildings is based on Problem-based learning [5, 58]. The whole process rests on the participants' ability to identify, discuss and articulate a problem. In this approach, there are no pre-established solutions, as it generally occurs in traditional learning; on the contrary, a procedure and some specific tools are made available to participants helping them detect a problem and establish all next steps

necessary to build a meaningful discourse on the given problem. As clearly proved, it is fundamental to have a guided procedure and guiding tools since a formative approach lacking guiding tools is not as efficient as a guided procedure, particularly for inexperienced learners who ignore human cognitive architecture [28]. Furthermore, according to Schmidt [46], human cognitive architecture is grounded in two crucial processes, that is the activation and the elaboration of prior knowledge which are the real bases of the suggested formative path, as previously discussed.

Map functionality as an assessment tool. The mapping approach proves to be an efficient assessment tool of the cognitive path by using the mapping components as indexes of the reasoning quality which emerges, in agreement with Hennessey [16], in the relationship between the product and the process respective creativity.

The indexes proposed have an open and enlargeable structure, easily adaptable to the participants' levels of knowledge and to the planned exercises complexity. It also bears mention that even numerical indexes never refer to a strictly analytical assessment.

The exercises results have emphasized that few concepts endowed with appropriate connections support a meaningful discourse better than numerous but badly connected concepts or a too general focus question. Therefore, gathering these indexes into three categories of assessment criteria aims to value the process whose meaningful discourse efficiency and effectiveness hinge on the balance between indexes of different categories. In this way, users will be able to employ such indexes to identify and correct any form of mechanical learning while trainers, supported by "Cmap Tools" software main functions, will be able to use these indexes to assess and compare the technical skills and the cognitive path creativity.

4.3 Future Research

Despite few architectural educators deny that technology is part of architecture, only a few pursue a real dialogue [56]. This study and its future developments intend to fill this persistent gap. A new proposal has been recently developed, this being financed by the European programme Marie Curie. This next experiment will deal with the theme of Energy Retrofit extending the scope of investigation beyond the historic contexts and buildings. Such a new investigation is meant to have a greater didactic articulation than the described experiences' one. In particular, four didactic programmes will be developed with a clear differentiation depending on their addressees: researchers/teachers, practitioners, undergraduate students and postgraduate students. This greater articulation will permit to enhance the interdisciplinary work since the participants will be grouped on the basis of the intentionality adopted when addressing the issue of energy retrofit. In this way, it will be possible to improve the development of cognitive tools dedicated to research, didactics and profession. In addition, this new experiment envisages developing the functional requirements a mapping software needs to have in the specific context of energy retrofit.

In the next future, the objective is to develop a dedicated software able to integrate the assessment indicators as software functions. At the moment, the new research programme is considering to hold some seminars with experts in artificial intelligence to discuss the possibilities of development of innovative didactic tools based on the meaningful learning activities and the mapping techniques.

Therefore, this future work represents a further contribution towards refining a new educational system based on the understanding and management of complexity, essential to prepare future designers and researchers to take on new challenges in order to encode a design technological culture fitting to contemporary society.

Acknowledgements

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Aims and scope

Today's design strongly seeks ways to change itself into a more competitive and innovative discipline taking advantage of the emerging advanced technologies as well as evolution of design research disciplines with their profound effects on emerging design theories, methods and techniques. A number of reform programmes have been initiated by national governments, research institutes, universities and design practices. Although the objectives of different reform programmes show many more differences than commonalities, they all agree that the adoption of advanced information, communication and knowledge technologies is a key enabler for achieving the long-term objectives of these programmes and thus providing the basis for a better, stronger and sustainable future for all design disciplines. The term sustainability - in its environmental usage - refers to the conservation of the natural environment and resources for future generations. The application of sustainability refers to approaches such as Green Design, Sustainable Architecture etc. The concept of sustainability in design has evolved over many years. In the early years, the focus was mainly on how to deal with the issue of increasingly scarce resources and on how to reduce the design impact on the natural environment. It is now recognized that "sustainable" or "green" approaches should take into account the so-called triple bottom line of economic viability, social responsibility and environmental impact. In other words: the sustainable solutions need to be socially equitable, economically viable and environmentally sound.

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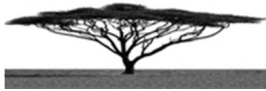
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