Exploring transformative pedagogies for built environment disciplines. The case of interdisciplinarity in Low Carbon Transition.

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The integration of transformative pedagogies into curricula is recognised as a strategy to deal with the new demands of complexity in learning, which include equipping future professionals with the necessary knowledge and skills to transition to a low carbon built environment. It requires a dedicated interdisciplinary learning environment. Creating this environment remains a challenge due to the lack of a learning tool to facilitate an interdisciplinary approach. Perhaps due to this challenge, interdisciplinarity within the context of Low Carbon Transition in the built environment has not been sufficiently explored. This study deals with this gap in the literature by developing a pedagogical approach founded on the combined use of Grounded Theory Method, Cognitive Mapping Technique and Meaningful Learning Activities. This paper focuses on the testing phase of this approach, which engaged researchers, postgraduate and undergraduate students. The findings promote a transformative pedagogy to explore the socio-technical dimension of the Low Carbon Transition. They point out the type of interdisciplinarity, which we need to integrate into traditional curricula, moving from vocabulary construction at the undergraduate level to exploration of different perspectives at the postgraduate level. Recommendations on the ways in which this approach could become common practice are also made.

Keywords: low carbon transition, design education, knowledge production, interdisciplinary collaboration, sustainable development.

Introduction

Scholars have recognized that an interdisciplinary approach is crucial for better understanding the complex implications of sustainable development (Allen, 2008; Brydon-Miller, 2018; Geels and Schot, 2010; Raven et al., 2016). These implications span the social and physical sciences within the built environment (Dedeurwaerdere, 2013; Khalili et al., 2015), and result in demands of complexity in learning (Allen, 2008; Ramirez, 2012; Ruge and McCormack, 2017; Wooltorton et al., 2015). Traditional learning approaches are arguably inappropriate for dealing with these emergent demands. Pedagogical aspects of equipping future built environment practitioners with the necessary skills and knowledge have thus emerged as significant challenges (Darbellay, 2015).

Several researchers have highlighted that the integration of transformative pedagogies into traditional curricula, could be a possible solution. Transformative pedagogy is defined as an activist pedagogy that empowers students to critically examine their beliefs in order to develop a reflective knowledge base and an appreciation of multiple perspectives (Ukpokodu, 2009). Here, teachers gain a new role as facilitators of learning who guide learners to understand the problems holistically (Wang et al. 2014; Minguet et al. 2011; Littledyke and Manolas 2010). They need to engage learners in an in-depth, Inquiry-Based Learning process (Pretorius, Lombard, and Khotoo 2016), which improves their abilities to examine complex socio-technical problems (Juárez-Nájera et al., 2010; Kemp and Nurius, 2015). Self-directed learning, which can also be supported by Information and Communication Technologies (Vassigh and Spiegelhalter 2014), and collaboration (Sibbel, 2009) emerge as important aspects of learning.

Putting these transformative pedagogies into practice remains a challenge (Bishop, 1992; Hartenberger et al., 2013; O'Byrne et al., 2015; Richter and Paretti, 2009; Sibilla, 2017). This challenge has now become a stimulating topic for researchers in the built environment disciplines, e.g. Architecture, Engineering and Urban Design, mainly in terms of preparing graduates to deal with complex problems such as Low Carbon Transition (LCT) to deliver sustainable development.

Literature Review

A large and growing body of literature has explored transformative pedagogies that deal with the compartmentalisation of knowledge in the context of the built environment. Domenica Iulo et al. (2013) made the case for graduating students to be ready to develop environmentally conscious designs, which require ecological literacy; and a comprehensive understanding of sustainability, natural systems, environmental responsibility, and energy-efficient design. They stressed that adapting existing courses is the most straightforward and fastest path to change. Sovacool et al. (2015) emphasised the importance of social and behavioural matters for energy modelling.

Other studies focussed on architectural engineering and design management. Hayden (2019) emphasised the need to transform pedagogy in learning building regulations, while Oliveira, Marco, and Gething (2018) focused on the changes needed to respond to the energy policy agenda. Rodriguez Bernal (2017) explored interconnected activities and learning-oriented assessment methods to enhance students' skills for collaborative learning. Davidson et al. (2010) have noted the barriers to updating engineering courses and curricula, including the significant amount of time that is required, the resistance to integrating new learning material and procedures into consolidated courses; and the lack of a sense of priority about such changes.

Other research paid attention to fostering inter-disciplinary collaboration through appropriate learning activities. Navarro et al. (2014) stressed that the development of activities that offer an opportunity to combine different branches of knowledge are important, but not very common in higher education. They emphasized initiatives like the Solar Decathlon, in which every participating team must represent multidisciplinary knowledge. Ochs, Watkins, and Boothe (2001) designed an innovative educational programme based on collaborative and project-based learning where many participants from diverse backgrounds, were called to participate. Papadopoulos and Hegarty (2017) pursued a cross-disciplinary and inquiries-based pedagogy, facilitating active learning to find and evaluate information from real-world and current problems, thereby helping students to learn how to learn. Students also dealt with multiple and often conflicting goals and values, working with constraints, and determining the most appropriate action to take, often in the absence of complete information or certainty.

Together, these studies illustrate the wide recognition that different pedagogical principles are required to achieve LCT, and therefore sustainability. However, some obstacles persist in the integration of such transformative pedagogies into traditional curricula. For example, all the above-mentioned learning experiences referred to "special learning events". They demonstrated the relevance of an interdisciplinary approach, but without compromising the existing curricula and programmes at the graduate and post-graduate level, which remain substantially mono-discipline focussed. Furthermore, these studies identified barriers to integrating transformative pedagogies into traditional curricula, but they have largely considered interdisciplinarity at a conceptual level. Hence, the transformation of curriculum has remained limited to the question of "*what*" to teach. It does not sufficiently tackle the related issue of "*how*" to foster interdisciplinarity to deliver LCT.

The limited studies on the "*how*", are focussed on individual disciplines, e.g. industrial design (Muller and Pasman, 1996; Oxman, 2004), and architectural design (Madrazo and Vidal, 2002). Their approach is particularly focused on enhancing skills for creativity and technical knowledge, which are key elements of design education in studios that remains the most common learning environment in this context (Crowther, 2013).

Low Carbon Transition, however, requires working across the boundaries between disciplines rather than in compartmentalised silos. Thus, a new pedagogical approach, which fosters interdisciplinarity as common practice, is needed. It necessitates tools, e.g. Cognitive Mapping Technique, that stimulate knowledge exchange and integration across different disciplines. Therefore, this paper aims to develop a pedagogical approach, which facilitates the exploration of the socio-technical dimension of Energy Retrofit as a means to achieving LCT, and to explore its potential to become a transformative pedagogy in the built environment disciplines.

Pedagogical Approach

The pedagogical approach combines: the Grounded Theory Method (GTM) (Charmaz, 2014), the Diverse Case Study Method (DCS) (Seawright and Gerring, 2008), the Cognitive Mapping Technique (CMT) (Novak, 1991; Novak, 2011) and Meaningful Learning Activities (MLAs) (Jonassen and Strobel, 2006). This combination allows an agile approach that can be implemented in different contexts to be developed. Table 1 provides the detail of each method and its role in the elaboration of the content and functionality of the pedagogical approach.

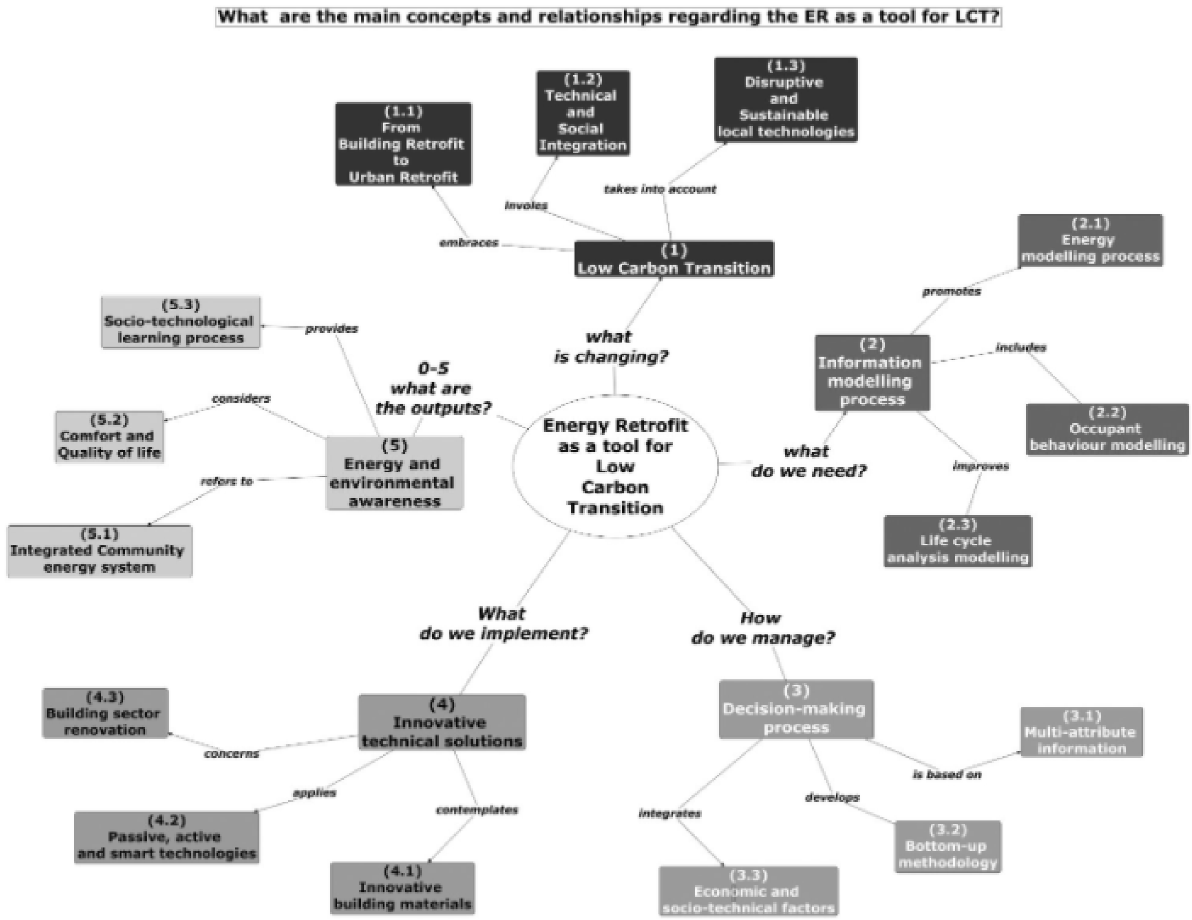
Table 1. Combined methods to develop the content and functionality of the pedagogical approach.

Method	Description	Scope	Pre-ordinated cognitive structure
Constructive Grounded Theory Method (Charmaz, 2014)	Developed a literature review of 213 journal papers	Main structure	Content
	Developed a literature review of 77 journal papers focused on the UK (saturation process)	Contextualization of the main structure	
Diverse Case Study Method (Seawright & Gerring, 2008)	Integrated case studies.	Provided 10 real-case studies with regards to the domains of knowledge defined.	
Cognitive Mapping Technique (Novak, 2011)	Elaborated a hierarchical organization of information in domain of knowledge	To define a set of focus questions which make clear the boundaries of exploration promoted. Each domain of knowledge represents a perspective of the investigation.	Functionality
Meaningful Learning Activities (Jonassen and Strobel 2006)	(i.e. observant and manipulative activity; constructive and reflective activity; Intentional and goal-directed activity; complex and contextual activity; collaborative and conversational activity)	To develop a reflective knowledge base and appreciation for multiple perspectives	

Cmap-Tools, which is a digital platform that facilitates cognitive mapping (Novak and Cañas, 2008), is utilised to implement this approach. Cmap-Tools is chosen instead of other tools such as Mindmap, Xmind, Coogle, GitMind, for the following reasons. Firstly, Cmap-Tools is designed to produce cognitive maps, which require an explicit focus question, rather than mental maps, which do not necessarily include clear connections between concepts or arguments. Secondly, the focus question facilitates the generation of targeted concepts. Thirdly, lines of argument are developed and illustrated by connecting each concept to others with linking phrases. These arguments are in fact responses to the focus question. Furthermore, Cmap-Tools and its servers are open-access. Thus, they are vital in disseminating our pedagogical approach as an Open Educational Resource across the Globe so that it can be easily replicated in other contexts.

The starting point for developing the pedagogical approach, was to create a pre-ordinated cognitive structure (Figure 1). It is composed of: a main focus question (i.e. what are the main concepts and relationships regarding Energy Retrofit as a tool for Low Carbon Transition?); five domains of knowledge and fifteen sub-domains (three for each domain), which include detailed information on case studies of energy retrofit projects. Together the domains and sub-domains of knowledge map the current interdisciplinary lines of research reported in the literature.

Figure 1. Pre-ordinated cognitive structure.



Method

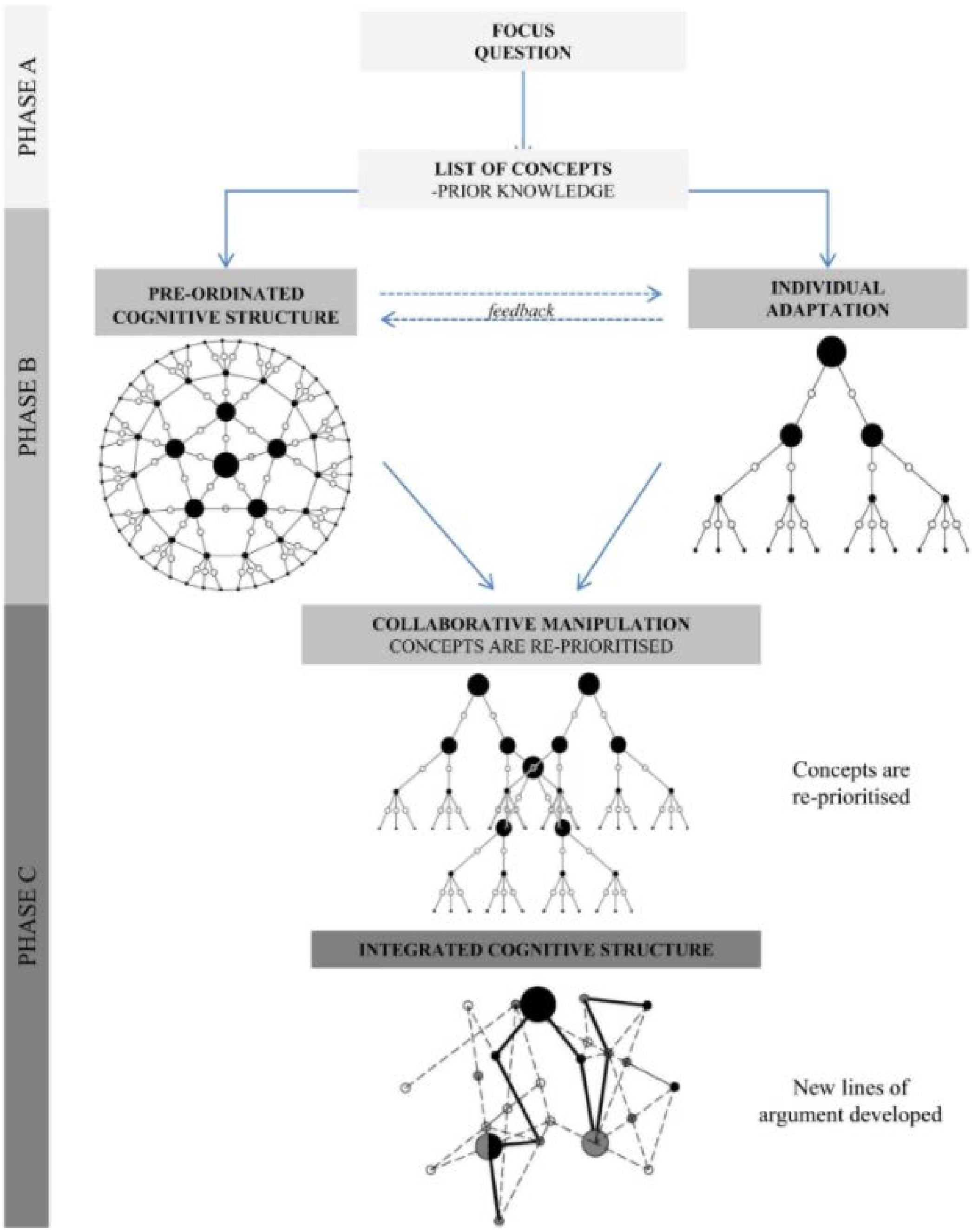
The method that was used to develop the cognitive structure was described elsewhere (Sibilla and Kurul, 2020; Sibilla and Kurul, 2019) and is out of the scope of this paper. Primary data for testing the pedagogical approach was collected through workshops, which were conducted over a five-month period. Each workshop took five hours. Sixty participants at three different levels of study were selected: twenty researchers, twenty postgraduate and twenty undergraduate students. The participant's interest in sustainable urban development and low carbon transition were among the selection criteria. Researchers were formally invited, while students were asked to express their interest to take part in the study. Students' CVs were used to assess their interest in the above-mentioned fields. Participants were from schools and departments of Architecture, Business, Built Environment, Climate Change and Planning from three universities in the South East of England.

The procedure was tested in the two phases that are illustrated in Figure 2. Phase A was completed individually. Each participant created a list of concepts in response to the main focus question (i.e., what are the main concepts and relationships regarding Energy Retrofit as a tool for Low Carbon Transition?). The list had to include 15 concepts related to the participant's prior knowledge in response to this question. Participants had to be able to describe each concept they listed. It was not necessary to provide scientific or documented explanations; real-life experiences were also accepted. Then, every participant was invited to present their list to the group, highlighting the concepts that better represented their interests.

Phase B was also completed individually. Each participant was given 30 minutes to familiarise themselves with the contents of the pre-ordinated cognitive structure. Later, they were asked to relate the main concepts of their lists into the pre-ordinated cognitive structure, and thus produce an individually adapted map; and to present this map.

Phase C was a collaborative process. Interdisciplinary groups of up to five participants were created. The facilitator asked participants to discuss their responses to the main focus question in order to move from individual/disciplinary maps to collaborative/interdisciplinary maps. The customised maps (Phase B) and the pre-ordinated cognitive structure were used to facilitate this move.

Figure 2. Phases of the testing procedure.



Feedback from participants was collected using a questionnaire at the end of the workshops. Their views on integrating this approach within traditional courses/modules were thus established.

A grid of observation was elaborated to consistently evaluate how each workshop participant interacted with the cognitive structure and each other. Table 2 describes the behaviour indicators in this grid. The expected outcomes in terms of learning and cognitive skills are also included.

Table 2. Grid of observation - behaviour indicators**.**

Behaviour indicators	Description	Learning and cognitive expected outcomes
Manipulation of Concepts	The user's level of understanding of each concept in the pre-ordinate framework is established.	To learn appropriate terminologies. To be able to share concepts within an interdisciplinary framework
Manipulation of relationships within a single domain of knowledge	The extent to which the user accepts the use of a concept within the pre-ordinated structure is observed.	To learn appropriate associations. To be able to provide information about a well-known concept following logic sequences
Articulation of concepts and relationships	The extent to which the user is able to produce a meaningful discourse starting from the pre-ordinated structure is observed.	To provide a new insight about a specific topic. To be able to expand knowledge about a well-known concept following logic sequences
Connections among domains of Knowledge	The extent to which the user is motivated to work through a multi-perspective is observed.	To learn from other perspectives To be able to integrate perspectives
New domains of Knowledge	The extent to which the pre-ordinated cognitive structure provides a framework for different perspectives and backgrounds is observed.	To learn interdisciplinary frameworks can be associated To be able to produce new research paths

Results

Table 3 shows the number of workshop participants and their distribution among both their level of study and discipline. The undergraduate (UG) students represent the architecture, engineering and planning disciplines. This distribution is perhaps a result of the engagement of these disciplines with ER and LCT early on in their degree programmes. Other disciplines are represented at postgraduate (PG) and research (R) levels.

Table 3. Number and distribution of workshop participants.

		Field of expertise					
		Architecture	Economics	Engineering	Planning	Others	Total
Category	Researcher	6	3	4	3	4	20
	Postgraduate	8	2	6	2	2	20
	Undergraduate	11	0	6	3	0	20
Total		25	5	16	8	6	60

Table 4 shows the users' behaviours observed through the individual and customised maps and reported through the grid of observation. In total, sixty individual, customised maps and fifteen collaborative and interdisciplinary maps were produced. They were the outcomes of the adopted pedagogical approach. The distribution of behaviour both within and between the levels of study (UG, PG and R) is illustrated.

Table 4 illustrates that participants at each level of study used the pre-ordinate cognitive structure differently. For example, the UGs mostly manipulated concepts (i.e. a-71%). The PGs' focussed on articulating concepts and relationships within a domain (c-80%). Neither the UGs nor the PGs manipulated the relationships (b). The behaviour of researchers was very different from that of UGs and PGs. They mainly concentrated on articulating the concepts and relationships between domains (d-65%). In some cases, the manipulation of relationships was also observed among researchers (b-13%). It should be noted that a new domain of knowledge was added to the cognitive structure only once.

Each category of participants used the pre-ordinate cognitive structure as the starting point for the knowledge transfer and integration processes. This structure provided an interdisciplinarity framework, which referred to users' prior knowledge. It was observed that when users from different disciplinary backgrounds selected to work on the same concepts or domains of knowledge, they quickly realised that their interpretations represented their backgrounds, and were able to start exploring ways in which they can integrate these separate lines of thought. These concepts (or domains of knowledge) were thus transformed. The level of transformation depended on the level of user's knowledge (e.g. researchers) and their backgrounds (e.g. architects).

Table 4. Grid of observation - behaviour mapped.

	Group	Background	a	b	c	d	e	Hierarchy of behaviours mapped
Undergraduate students	U1	2A+2C + D	14	–	–	1	–	Prevalent – a
	U2	2A + C+D	6	–	2	–	–	Secondary – c
	U3	2A + D	3	–	–	3	–	Absent – b and e
	U4	3A + C	–	–	9	–	–	
	U5	2A + 2C	14	–	–	–	–	
	Percentage distribution		71%	0%	21%	8%	0%	
	Group	Background						
Postgraduate students	P1	A + B+2C + E	–	–	10	5	1	Prevalent – c
	P2	2A + B+C	1	–	4	2	–	Secondary – d
	P3	A + C+D + E	–	–	8	3	–	Absent – b
	P4	2A + C	–	–	8	–	–	
	P5	2A + C+D	–	–	19	–	–	
	Percentage distribution		2%	0%	80%	16%	2%	
	Group	Background						
Researchers	R1	A + B+C + D	–	3	–	8	–	Prevalent – d
	R2	A + C+D	–	1	–	9	–	Secondary – a
	R3	2A + C+2E	1	3	–	17	–	Absent – c and e
	R4	A + B+C+2E	6	1	–	5	–	
	R5	A + B+D	7	–	–	1	–	
	Percentage distribution		23%	13%	0%	65%	0%	

Notes: A: Architecture; B: Economics; C: Engineering; D: Planning; E: Others (Conservation, Geography, Ecology, Sociology). a: Concept manipulated; b: Relationships manipulated; c: Articulation of concepts and relationships within a domain; d: Articulation of concepts and relationships between domains; e: New Domains of Knowledge.

Other observations on the users' behaviours include the ways: undergraduate students manipulated the concepts; postgraduate students articulated concepts and relationships within a domain; and, researchers articulated concepts and relationships between domains of knowledge.

Table 5 illustrates how the undergraduate students, who collaborated using the pre-ordinated cognitive structure, manipulated the concepts. For example, each undergraduate student focused on a specific concept (e.g. reduce waste, social relationship and governance) that was also on their concept list when they were individually elaborating their customised maps. Once they were more familiar with the pre-ordinated cognitive structure, they amalgamated their individual concepts into the same concept on the pre-ordinated structure (e.g. local industries). The next step was a group discussion on the meanings of both the concepts that the participants listed at the beginning and those included in the cognitive structure in order to produce a collaborative map. Group behaviours during this discussion are also mapped on Table 5. For example, groups were sharing definitions of technical terminology at the beginning of their discussions.

As a result, each participant was engaged in a learning activity that expanded their knowledge of the concepts. They were also able to integrate their reciprocal knowledge using their individual concept lists as the bases for a collaborative semantic structure. However, it should be noted that the opportunity for an interdisciplinary semantic structure to emerge, could not be exploited as the duration of the workshops was dedicated to discussing the meanings of concepts. The groups that included at least a member with a planning background, i.e. U1, U2 and U3, were the ones that expanded the discussion from technical interdisciplinarity to a socio-technical one.

Table 5. Example of manipulation of concepts produced by undergraduates

	Prior knowledge	After reading the pre-ordinated cognitive structure	Behaviours mapped
U1	Reduce waste	Local industries	• Sharing technical disciplinary lexicon • Establishing the level of interdisciplinary interactions, in terms of what type of interdisciplinary topic affects the position of participants • Prioritizing disciplinary concepts in order to produce interdisciplinary perspectives
	Social relationship		
	Governance		
U2	Environmental aspects	Social justice	
	Health and wellbeing		
U3	Urban fragmentation	Socio-technical factors	
	Sustainability		
	Territorial connections		
U5	Renewable energy	Integrated energy systems	
	Solar energy		
	Innovative roof systems		
	Natural environment	Environmental performance	
	Urban CO_2 emission		
	Mitigation pathways		

The postgraduate students articulated the concepts and relationships within a single domain as illustrated in Table 6. Here, the socio-technical interdisciplinarity concerning LCT is evident. In each group, the participants utilised the opportunity to integrate their individual perspectives into a unitary framework. While the discussions started from different domains of knowledge, i.e. 1, 2 and 3, in different groups, overarching concepts provided several opportunities for integration into a unique cognitive profile. Indeed, all three groups focused on the role of the people. In the first case, the exploration centered around immigration and energy culture. In the second case, it was on user engagement in the decision-making process; and in the last case, it was on public attitudes and behaviours. These concepts represented the opportunity to establish transversal connections among groups. Figure 3 shows the result of the discussion mapped between PG1, PG2 and PG3, offering further socio-technical interdisciplinarity pathways.

Figure 3. Example of discussion mapped between PG1, PG2 and PG3.

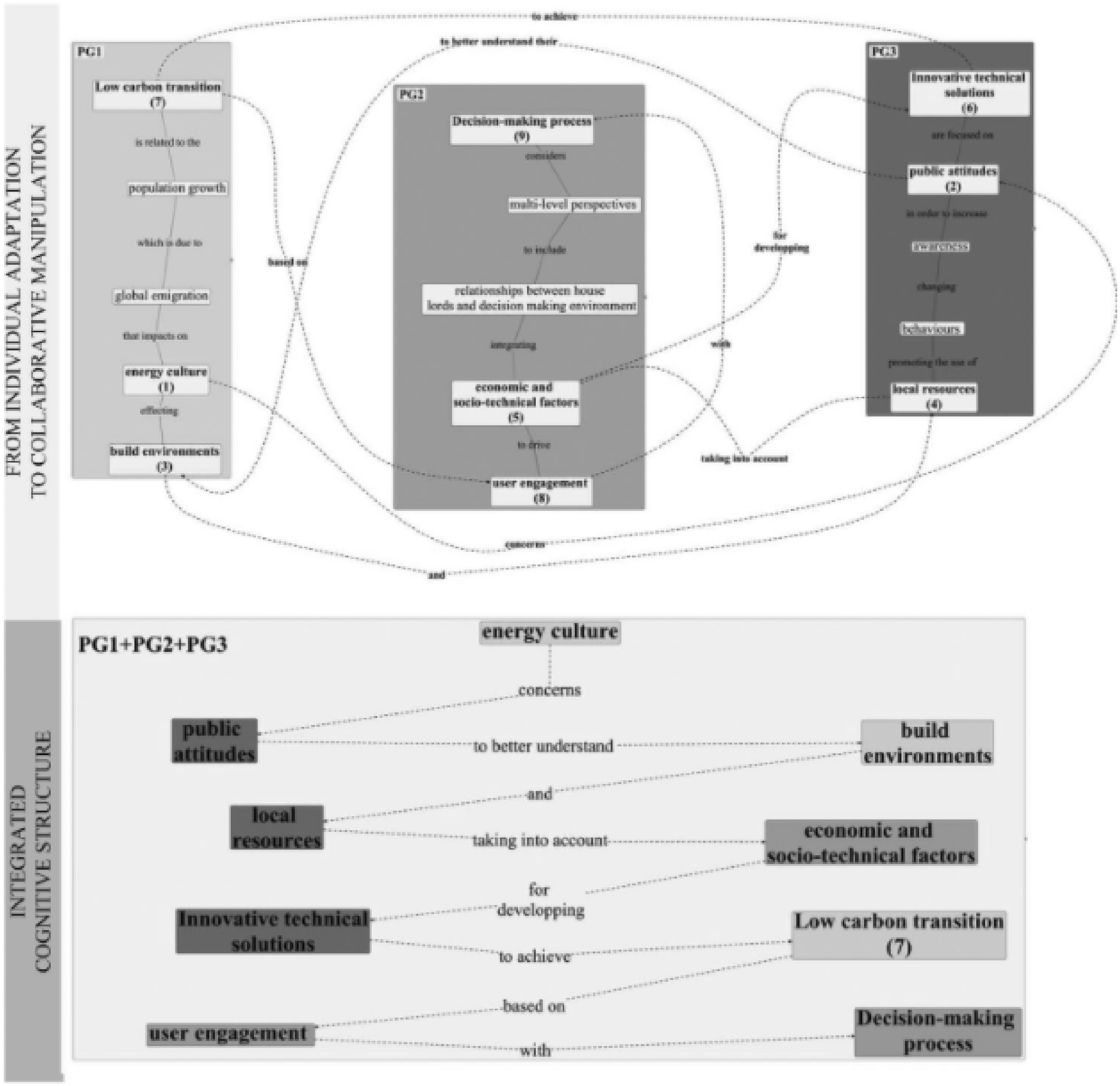


Table 6. Example of articulation of concepts and relationships within a single domain carried out by postgraduates.

Concept (C) and Relationship (R)	PG1	Domain of knowledge and its articulation	PG2	Domain of knowledge and its articulation	PG3	Domain of knowledge and its articulation
C	Low carbon transition	1	Decision-making process	3	Innovative technical solutions	4
R	is related to the	New sentences	considers	New sentences	are focused on	New sentences
C	population growth		multi-level perspectives		public attitudes	
R	which is due to		to include		in order to increase	
C	global emigration		relationships between communities and decision-making environment		awareness	
R	that impacts on		integrating		changing	
C	energy culture		economic and socio-technical factors	3	behaviours	
R	effecting		to drive	New sentences	promoting the use of	
C	built environments		user engagement		local resources	

Table 7 shows the researchers' articulation of the concepts and the relationships between the knowledge domains. The researchers worked collaboratively to prioritise relevant common concepts. They were mainly engaged with extrapolating interdisciplinary relationships from the knowledge domains that were included in the pre-ordinated cognitive structure. Similarly to the PGs students, after elaborating a collaborative map, researchers established additional relationships through discussions within their groups. These discussions enabled the participants to consider the implications of ER as a tool for LCT from different disciplinary perspectives.

Table 7. Example of articulation of concepts and relationships between domains carried out by researchers.

Concept (C) and relationship (R)	R1	Domain of knowledge	R2	Domain of knowledge	R2	Domain of knowledge
C	Low carbon transition	1	Energy modelling process	2	a multi stage development process	3
R	involves		analyses		considers	
C	relationships between buildings and people	2	low carbon transition	1	data	2
R	to improve		using		which refers to	
C	energy and environmental impact	4	economic and socio-technical factors	3	stakeholders' perspective	4
R	by carrying out		applied to		to issue	
C	social experiment	5	innovative building materials	4	energy social policies	5
R	taking into account		enhancing		through	
C	financial mechanism	3	integrated energy systems	4	participatory process	5
R	in order to achieve		as		to carried out	
C	smart city imaginary.	1	decentralized energy systems.	5	low carbon transition	1

For example, groups R1, R2 and R3 discussed the concept of "low carbon transition". This concept was included in all collaborative maps in different hierarchical levels. It was conceptualised from different disciplinary perspectives as illustrated in Figure 4. Cognitive mapping enabled these groups to amalgamate their own concepts and conceptualisations in order to provide a shared description of this common concept. Hence, each group was informed about a new perspective, which can be useful in drawing on original interdisciplinary research paths.

Figure 4. Example of discussion mapped between participants in R1, R2 and R3.

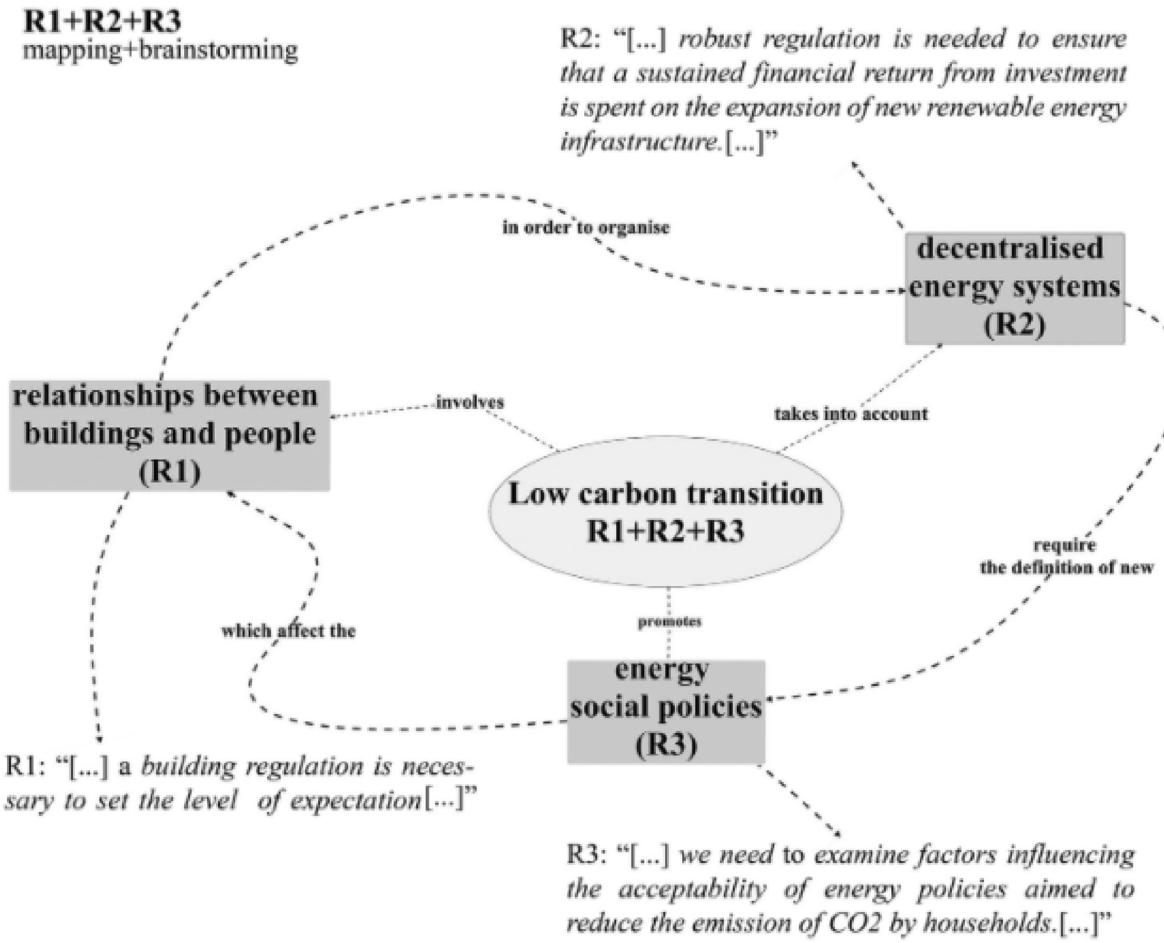


Figure 5 shows the results of the feedback questionnaire that each participant completed at the end of the workshops. 84.5% of the respondents provided positive feedback. Results disaggregated at the study level, show that the undergraduates are the most critical with 29% of the respondents providing relatively negative feedback. On the contrary, 96% of the researchers and 86% of the postgraduates are satisfied with the proposed pedagogical approach.

Figure 5. Percentage responses distribution from the questionnaire

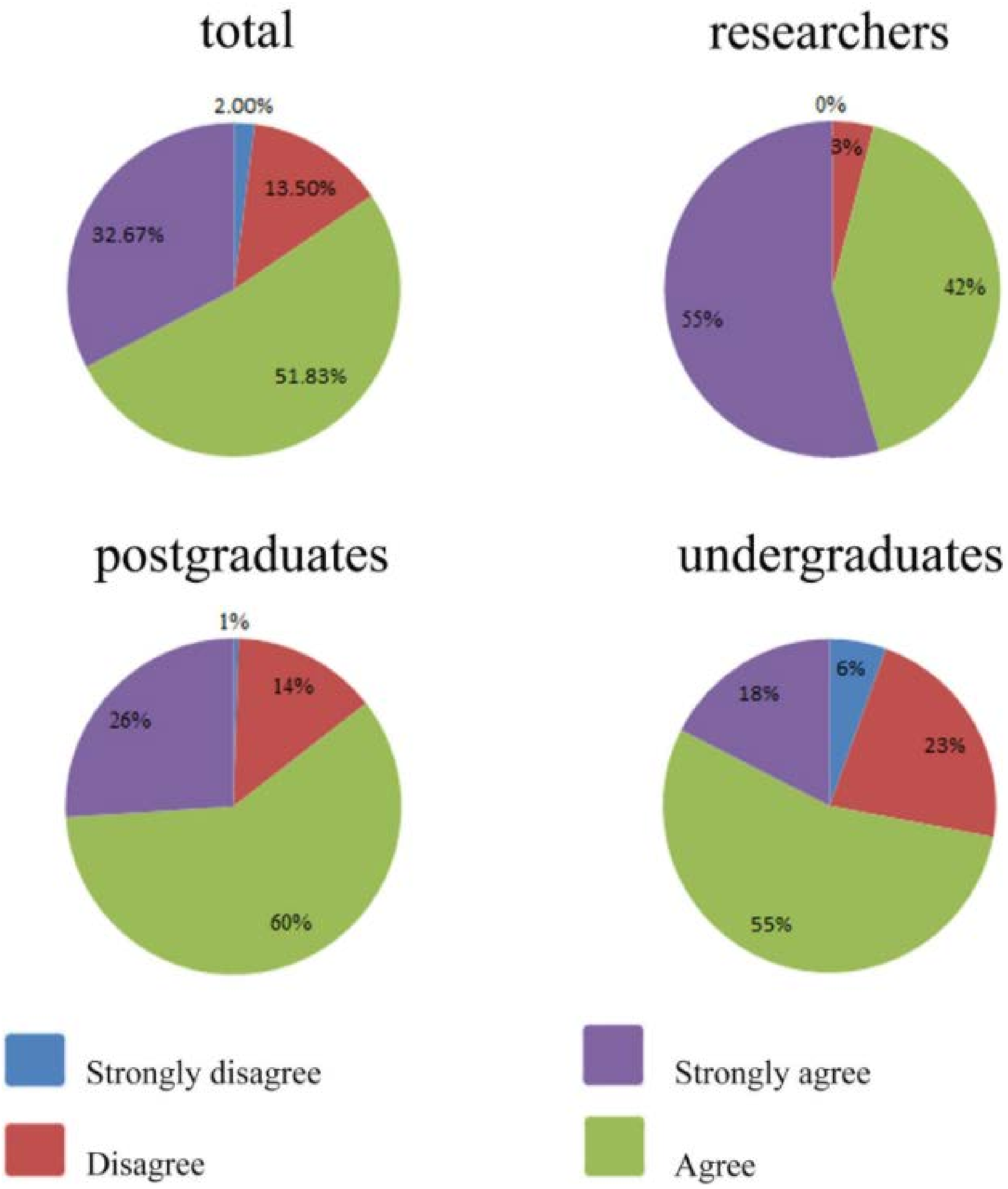


Table 8 shows the participants' responses to each question. Q1 reveals that the majority of the participants used Cognitive Mapping Technique for the first time. A very small proportion of the participants had used some form of mapping before. Even then, the majority had used mental maps rather than cognitive maps. Therefore, the proposed approach was novel to the participants.

Researchers almost exclusively provided positive feedback on using cognitive mapping to explore a complex topic. The postgraduate students' views were divided on this matter, although they concurred that producing a list of concepts helped them understand how to use their prior knowledge (Q2). A large proportion (40%) of UG students did not consider that this pedagogic approach helped them to understand how their existing knowledge could be integrated into a more complex, existing framework (Q7).

Table 8. Participants' responses

		Count			
Question	Category	Strongly disagree	Disagree	Agree	Strongly agree
Q1 – This is the first time I have used this approach	Researchers	0	1	7	12
	Postgraduates	0	0	8	12
	Undergraduate	0	3	5	12
Q2 – I consider that the exercise of producing a list of concepts helped me to understand how to use my prior knowledge.	Researchers	0	0	8	12
	Postgraduates	0	3	16	1
	Undergraduate	1	3	13	3
Q3 – I consider that the exercise to integrate my knowledge with the Cognitive Tool was helped me to find out connections among concepts	Researchers	0	1	8	11
	Postgraduates	1	4	13	2
	Undergraduate	1	3	14	2
Q4 – I consider that the exercise to integrate my knowledge with the Cognitive Tool helped me to identify relevant issues in brief time.	Researchers	0	4	8	8
	Postgraduates	0	5	8	7
	Undergraduate	1	5	10	4
Q5 – I consider that the comparison and discussion of the resulting cmaps with others helped me to exchange information.	Researchers	0	0	11	9
	Postgraduates	0	2	16	2
	Undergraduate	1	2	11	6
Q6 – I consider this approach to be useful for understanding the opportunities to work collaboratively.	Researchers	0	0	9	11
	Postgraduates	0	3	10	7
	Undergraduate	3	3	13	1
Q7 – I consider that this approach helped me to understand how to integrate my knowledge into a more complex, existing framework.	Researchers	0	0	8	12
	Postgraduates	0	4	9	7
	Undergraduate	0	8	11	1
Q8 – I consider this approach was useful for better understanding the relevant concepts and their relationships.	Researchers	0	2	7	11
	Postgraduates	0	2	14	4
	Undergraduate	1	3	15	1
Q9 – I consider this approach was useful for stimulating a meaningful dialogue with other participants.	Researchers	0	0	9	11
	Postgraduates	0	5	10	5
	Undergraduate	2	11	5	2
Q10 – I consider the Cognitive Tool as a useful tool to integrate interdisciplinary topics into the traditional courses/modules.	Researchers	0	0	8	12
	Postgraduates	0	0	15	5
	Undergraduate	1	4	12	3

Again, the researchers and postgraduates were substantially positive about the value of the Meaningful Learning Activities supported by the pre-ordinated cognitive structure, while the UG students were most critical. They also emerged as the more resistant category to adopting Cognitive Mapping as a tool for integrating interdisciplinary topics into the traditional courses/modules.

Discussion.

Previous studies have stressed the importance of the interdisciplinary approach to deal with the socio-technical complexity of sustainable development (Allen, 2008; Brydon-Miller, 2018; Geels and Schot, 2010; Raven et al., 2016). However, putting interdisciplinarity into practice continues to be a challenge due to the lack of dedicated tools and appropriate learning environments (Bishop, 1992; Hartenberger et al., 2013; 'O'Byrne et al., 2015; Richter and Paretti, 2009). Therefore, this study has developed and tested a new pedagogical approach to foster transformative pedagogies in order to equip future built environment professionals with appropriate skills and knowledge to transition to low carbon. The findings show that our approach is one such tool, because it facilitates the consideration of individual concepts or domains of knowledge from different disciplinary perspectives by helping the users visualise where the different discourses overlap or diverge. These discourses and opportunities to integrate different perspectives should be included into traditional curricula of built environment disciplines so that working across disciplinary boundaries becomes common practice.

The pedagogical approach allows participants to be engaged in interdisciplinary discussions at different levels. For example, undergraduates discussed specific concepts in order to clarify their meanings. Postgraduates focused on a specific domain of knowledge to further elaborate on it, while researchers established new relationships between several domains of knowledge.

In line with Sovacool et al.'s (2015) results, our findings contribute to operationalising the synergic integration of social and technical data, orienting energy research around specific problems, and encouraging diverse perspectives to explore problems simultaneously. This synergic integration becomes the opportunity for developing a new set of cognitive skills such as manipulating the pre-ordinated cognitive structure until a meaningful discourse emerges. Findings reveal that the pre-ordinated cognitive structure allows learners to visualise the process in progress, reducing the cognitive load of having to memorise external information. Additionally, it acts as a knowledge framework to integrate personal perspectives into an interdisciplinary framework, and to self-assess where one's existing knowledge is located within it. Therefore, the understanding that knowledge may, at times, be compartmentalised emerges as the first realisation towards the co-production of knowledge. It is clear that these compartments are not static. Instead, they evolve through the different ways in which knowledge is exchanged in different inter-disciplinary learning environments, as illustrated by the different behaviours displayed by participants at different levels of study in Tables 4, 5, 6, and 7. Thereby, our pedagogical approach supports a new thought process which enables the participants to rethink their disciplinary identities, rather than remain in an assembly of existing disciplines, as suggested by Darbellay (2015).

Our approach differs from prior empirical experiences, which focused on pedagogical approaches that deliver discipline-specific curricula. Although innovative, the results of these experiences are not within the boundaries of our exploration. For example, Hayden (2019) developed a pedagogical approach based on an innovative visual learning tool to study building regulation compliance in an architectural technology module. This tool enables the students to more easily manage the complexity inherent in this topic, but the students do not have the opportunity to modify the framework. This approach can be defined as traditional, expert-driven knowledge transfer (Biberhofer and Rammel, 2017). Rodriguez Bernal's (2017) pedagogical approach aimed at shifting the focus from a competency-based model to a student-centred model in another architectural technology module. The goal was to foster cooperation as an essential skill to deal with conflict in real-word practice. Even so, this approach drew inspiration from the traditional design-cycle framework.

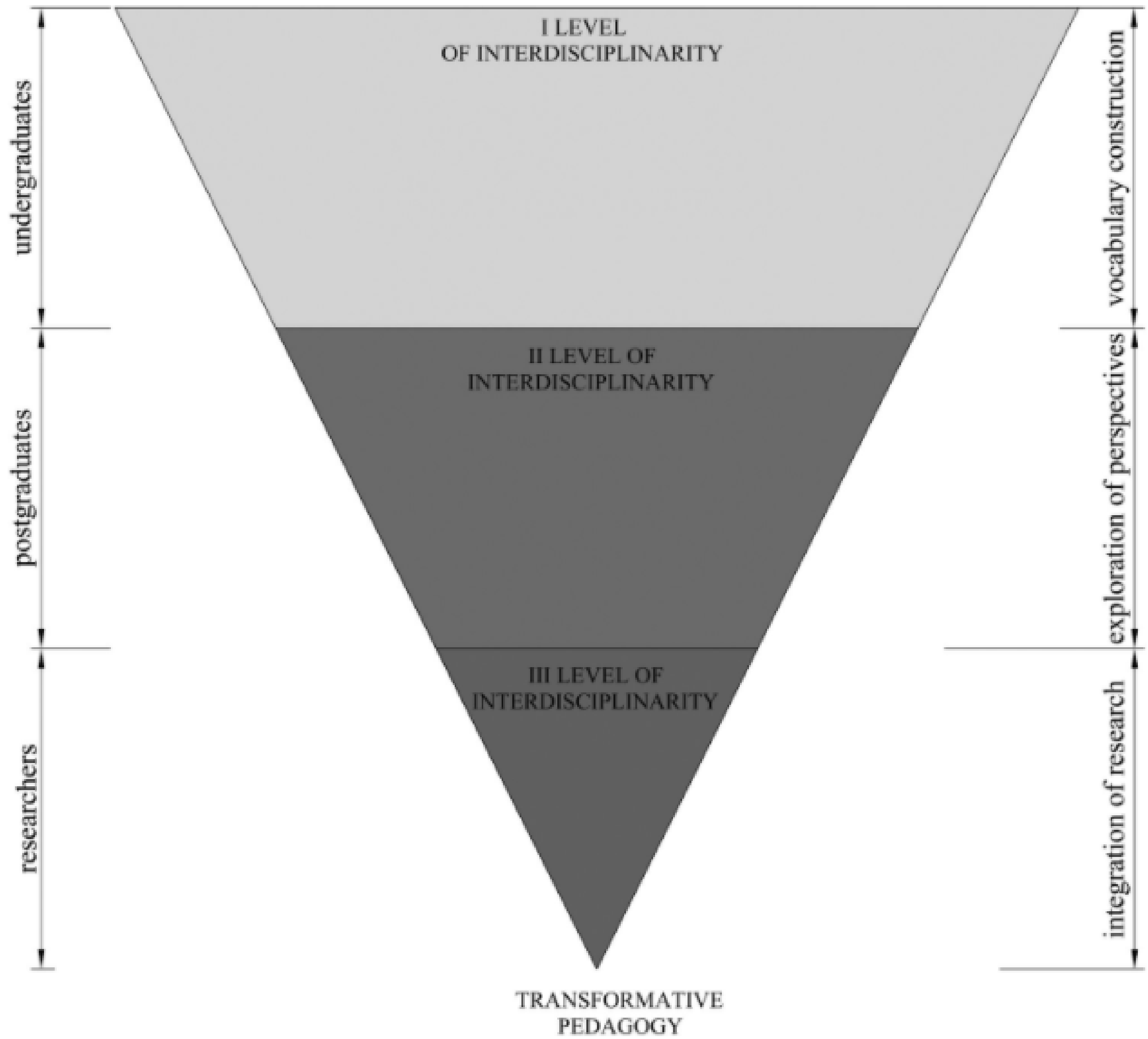
In contrast, exploring transformative pedagogy means to destabilise the current framework in order to rethink disciplinary identities and pursue new socio-technical solutions. For example, the pre-ordinated cognitive structure includes technical topics such as building regulations. However, the aim is to move beyond compliance by promoting a new role for existing buildings in the low carbon era. This transformation requires both a new generation of rules and the articulation of the design-cycle. Findings illustrate that the proposed approach facilitates the open dialogue and the co-creation of knowledge in order to deal with the complex implications of sustainable development, as called for by Biberhofer and Rammerl (2017).

It is also useful to stimulate disciplinary knowledge to come out of isolation, which does not mean to produce universal knowledge. Instead, it means to understand how one's disciplinary approach compares with other perspectives (Bishop, 1992). Our pedagogical approach enabled this comparison through a sequence of cognitive exercises, where a set of maps were produced and shared in a permanent cycle of adaptations. Our pedagogical approach followed Richter and Paretti, (2009) by encouraging the development of alternative knowledge paths rather than the provision of a package of information. In other words, interdisciplinarity was facilitated by enabling a group co-create new knowledge that was integrated across disciplinary boundaries.

Such co-creation of knowledge does not simply mean a general assembly of branches of knowledge. It requires flexible empirical approaches that can be adopted to various interdisciplinary experiences promoted as special events (e.g. Navarro et al., 2014). Here, the ambition is to promote a method in order to make interdisciplinary education programmes common practice and thus the re-conceptualisation of professional practice (Papadopoulos and Hegarty, 2017). The significance of associating the CGTM with the CMT and MLAs lies in this ambition. The proposed approach may become a response to the lack of robust procedures which could identify possible connections among disciplines, because it allows continuous adaptation of content and cognitive structure. More importantly, it can reduce the amount of time needed to elaborate learning materials, which is one of the main barriers to innovation in the curricula (Davidson, 2010).

Consequently, our pedagogical approach could accelerate the integration of a transformative pedagogy, which is dedicated to interdisciplinary and socio-technical aspects of Low Carbon Transition, into traditional curricula at different levels of study (Figure 6). Unlike Iulo (2013) who presented a model curriculum where environmental design becomes a thread which connects the five years of the programme, we do not envisage Energy Retrofit to become a thread that runs through these levels. Our ambition is to foster inter-departmental collaboration, where students with different backgrounds are engaged in truly interdisciplinary learning activities that are mandatory. Hence, we respond to Biberhofer and Rammel's (2017) question by considering "*what*" and "*how*" to teach in an interdisciplinary learning environment.

Figure 6. Integration of the pedagogical approach within traditional curricula.



Limitations of this study should also be acknowledged. At this stage, the same procedure and tool were adopted for participants at all levels of study. However, the results showed that the level of interdisciplinary collaboration varies according to the level of participants' prior knowledge. Additionally, they revealed a stark difference between the undergraduate students' perceptions of the approach and those of the postgraduate students and researchers. Our proposed approach was particularly appreciated by researchers and postgraduates as it stimulated collaboration and helped create an appropriate learning environment. We argue that the differences in opinion were informed by the level of study, and the associated sophistication and consolidation of knowledge. Hence, we acknowledge that the pre-ordinated cognitive structure must conform to the level of prior knowledge in order to enhance the proposed approach.

Conclusions.

This study explored the main features of a new pedagogical approach, which aims to enable future built environment professionals deal with the socio-technical complexity of Low Carbon Transition. It developed a pre-ordinate cognitive structure as a tool to facilitate the integration of different backgrounds and levels of knowledge.

Findings pointed out the adaptability of the pedagogical approach, which could be suitable for both deductive methods (e.g. lectures) and inductive methods (e.g. the design studio). In the former, this pedagogical approach may facilitate the extension of the traditional analytical and technical competences of engineers into the social sciences domain. In the latter, where problem-based learning is already used to stimulate disciplinary-individual creativity, this approach may be considered as an opportunity to enhance interdisciplinary collaborative work.

It is important to point out that the application of this pedagogical approach in architectural and engineering design does not seek to substitute the signature pedagogy of the design studio, which characterises these disciplines. On the contrary, the scope is to reinforce the term "studio" by transforming it into a place of learning where cultural and pedagogical activities are developed (Crowther, 2013); and, where knowledge and skills are integrated and applied. The integration proposed herein may be considered as a transformative pedagogy to help learners construct their knowledge on how they can contribute to the definition of a low carbon society in an interdisciplinary context.

Further research in this direction is suggested. The pedagogical approach may be fully appreciated if the pre-ordinated cognitive structure is adapted to the specificity of the learning context. In other words, the disciplinary heterogeneity of the workshops must be planned before completing the pre-ordinated structure. By doing so, the selection of its contents, based on the combined use of Constructive Grounded Theory and Diverse Case Method, can be more targeted.

In conclusion, this study combined the use of Constructive Grounded Theory Method (CGTM), Diverse Case Method (DCM), Cognitive Mapping Technique (CMT) and Meaningful Learning Activities (MLAs) in order to develop a pre-ordinated cognitive structure as an Open Education Resource. Our pedagogical approach is offered to scientific communities for implementation and adoption to specific interdisciplinary programmes in Higher Education.

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