PROJECTE DE TESI

LA TRANSDISCIPLINARIETAT PER A LA SOSTENIBILITAT EN ELS ESTUDIS D'ENGINYERIA

Doctorat en Sostenibilitat

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Barcelona, maig de 2013

'The world has problems, but universities have departments'
(Brewer, 1999)

'If I were asked to define our times, in few words, I would say that we have reached a point in our evolution as human beings, in which we know very much, but understand very little'
(Max Neef, 2005)

Índex

1 Dades d'identificació

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2 Títol provisional de la tesi

La transdisciplinarietat per a la sostenibilitat en els estudis d'enginyeria

3 Resum

El projecte de tesi planteja la necesitat emergent d'introduïr de forma eficient la transdisciplinarietat com a un dels principis vertebradors de l'educació en enginyeria per a la sostenibilitat en la UPC. Aquesta necessitat s'analitza a partir dels considerats principals reptes del procés transdisciplinari, que es poden anomenar com: *creuar les fronteres* (entre disciplines, entre acadèmia i societat, entre formes de generació de coneixement, entre sistemes pedagògics i de comunicació); '*not for society, but with society*'[1]; i *la integració dels coneixements*, relacionats amb la resolució d'un problema complex.

La discussió referent a aquest anàlisi segueix als capítols del 5.1 al 5.5., on es revisa el requeriment d'estrategies de resolució de problemes complexes de sostenibilitat; les diferencies entre els diferents enfocaments '*cross-disciplinars*' (pluri-, multi-, inter- i trans- disciplinarietat); una perspectiva històrica i també des de la transdisciplinarietat, de la generació de coneixement; i les diferents tendències i aproximacions existents a la transdisciplinarietat.

En el punt 5.6, la transdisciplinarietat es contemplada com un component crític de la ciència de la sostenibilitat, pel que fa a l'establiment de la col·laboració activa amb les parts interessades de tota la societat i a la orientació a la resolució de problemes complexos, socialment rellevants.

Un especial èmfasi es posa en el paper de la transdisciplinarietat en l'educació superior. Es revisen les habilitats i competències adequades, així com diferents aproximacions a la transdisciplinarietat, en entorns d'educació superior diversos. Finalment es realitza una relació de diferents activitats dutes a terme en universitats arreu del mon. L'Article 14 de la Carta Charter of Transdisciplinarity[2], es rellevant en aquest punt: "*Rigor, openness, and tolerance are the fundamental characteristics of the transdisciplinary attitude and visión (…)*".

En l'àmbit de la UPC, la proposta de tesi reflecteix la preocupació expressada per la comunitat universitària i reflectida en la segona fase del Pla UPC Sostenible 2015, que aborda la relació entre la universitat i la societat desde la ciència de la sostenibilitat, establint estratègies en les activitats acadèmiques i administratives de la universitat, a través de la pràctica transdisciplinar.

En el capítol 6 es planteja el pla de treball de la tesi, que es basarà en dos tipus d'accions. Per una banda el treball de camp consistirà en el disseny i realització d'entrevistes i enquestes (questionaris i mapes conceptuals) a realitzar als actorss prèviament identificats. Per altra banda es realitzarà una immersió en activitats acadèmiques i divulgatives en transdisciplinarietat, per tal d'assolir expertesa interaccional. En base a la recerca i conjuntament amb tota la informació que regularment genera aquest tema (bibliografia, publicacions, congressos i conferències) es tractarà de definir l'estructura idònia per a assolir l'orientació transdisciplinaria en els estudis d'enginyeria, observant les estratègies, les metodologies didàctiques i els recursos físics més adequats.

[1] Scholz a INIT, 2012. Veure punt 5.1.
[2] Charter of Transdisciplinarity. First World Congress of Transdisciplinarity, Convento da Arrabida, Portugal, 1994, Article 14. Disponible a: nicol.club.fr/ciret/english/charten.htm.

4 Objectius

L'objectiu global de la tesi és millorar l'educació en sostenibilitat a la Universitat Politècnica de Catalunya UPC-BarcelonaTech (UPC), tot aportant una revisió crítica de la contribució de la transdiciplinarietat a l'aprenentatge de l'enginyeria, per tal de plantejar alternatives a la pràctica educativa i universitària de la sostenibilitat.

L'objectiu passa per introduïr de forma eficient la transdisciplinarietat als ensenyaments de la UPC. La revisió bibliogràfica demostra la mancança d'aquest tipus d'aproximació i la necessitat d'establir-lo en els programes educatius existents per tal de preparar els enginyers i científics per a operar amb eficàcia i compromís en un entorn complex. El Pla Sostenible 2015, que recull el pacte de la UPC cap a la sostenibilitat, referma en la seva segona fase la necessitat i vocació d'interacció i compromís amb la societat de la UPC.

Donada l'amplitud de l'objectiu global, aquest es dividirà en objectius més concrets que són:

1. Explorar que representa la transdisciplinarietat, com es perceb en la comunitat educativa i quina és la seva relació amb la sostenibilitat.
2. Analitzar la necessitat de la inclusió de la transdisciplinarietat en la formació de l'enginyeria i en que consisteix.
3. Detectar mancances d'aquesta competencia als estudis de la UPC, des del punt de vista dels programes i des del punt de vista del professorat.
4. Identificar estratègies i sistemes pedagògics i d'avaluació adients i eficients en el procés ensenyament-aprenentatge, que facilitin la introducció de la transdisciplinarietat en el marc de l'EEES.
5. Proposar què i com introduir la transdisciplinarietat per a la sostenibilitat a la pràctica de la UPC.

5 State of the art

5.1 The need of transdisciplinarity

In our world characterised by rapid change, uncertainty and increasing interconnectedness, science is increasingly, called to contribute to the solution of persistent, complex problems, not only environmental issues such as climate change and biodiversity loss, but also related issues such as poverty, security and governance. For all of these problems, the increase in availability of scientific knowledge has not been reflected in decisive action to overcome the demand for knowledge to contribute to the solution of societal problems.

Knowledge demands from society are about issues that call for change in societal practices. These can be complex matters, "where facts are uncertain, values in dispute, stakes high and decisions urgent. In such a case, the term 'problem', with its connotations of an exercise where a methodology is likely to lead to a clear resolution, is less appropriate" (Funtowicz & Ravetz, 1993: 744). The situation is not solved, as frequently attempted by creating supposed teams conformed of specialists in different areas, around a given problem. With such a mechanism one can only hope to achieve an accumulation of visions emerging from each of the participating disciplines. As Max Neef stated '*an integrating synthesis is not achieved through the accumulation of different brains. It must occur inside each of the brains and, thus, it's needed to orient higher education in a way that makes the achievement of such a purpose possible*' (Max-Neef, 2005: 5). The 'problem' situation demands a problem-solving strategy that is achieved through transdisciplinary orientation in research, education and institutions aims (Jäger et al., 2008).

In a correspondence to the journal Nature in 2010, a group of international scientists claimed funding for transdisciplinarity scientific collaboration, that is capable of properly understand the ways in which our technology impacts the complex, interconnected systems we depend on, against rely on maintaining and reinforcing only disciplinarity sciences (Vasbinder et al., cited in Jahn, 2012). Interventions like this explain the perceived need of the scientific community to address their work in a collaborative framework that coheres with the complex structure of pressing problems. Also, remind us that, after years of debate, cultures and practices have still not been established in that way.

However, the interest in transdisciplinarity increases. At the 2012 Sustainability Summit at the Leuphana University of Lüneburg (Leuphana, 2012), Thomas Jahn started his intervention pointing out that that publications on transdisciplinarity have hugely increase in the last mid decade. Since the first publication of transdisciplinarity is 1972 (Jantsch, 1970), we see some increase from the Conference on Environment and Development in Rio de Janeiro in 1972, where the importance of science to stakeholder development was highlighted and the need to transform research by involving stakeholders and promoting mutual learning between science and life-world was stressed (Hirsch Hadorn et al., 2006).

After 40 years of intensive scholarly discourse a universally accepted definition is not available and consequently, approved equally guiding standards for transdisciplinary researchers, program managers and donors are also lacking. One reason could be that, at first sight, transdisciplinarity appears to be a rather elusive concept. Yet where concepts or ideas are not properly defined, the risk is that a rather shallow interpretation prevails—a fate that paradigmatically befells the notion of sustainability. The likely damage that can occur with such a mainstreaming is that the true challenges of transdisciplinary collaboration are underestimated (Jahn, Bergmann, & Keil, 2012).

Beyond cross-disciplinary methodologies (Scholz, cited in Klein, 2001: 250), transdisciplinarity is transcending, transgressing, and transforming, it is theoretical, critical, integrative, and restructuring but, as a consequence of that, it is also broader and more exogenous (Hadorn et al., 2010). Thus by bringing about mutual learning, collaborative research, and problem solving among business, government and civil society, can serve as an important guiding concept for sustainability science and practice. Transdisciplinarity emerged to counteract the tendency of disciplines to place rigid boundaries around knowledge, and to separate it into artificial compartments. Building transdisciplinarity requires a strong commitment to flexibility and rejection of the temptation to institutionalize transdisciplinary excursions (Russell, Wickson, Carew, 2008).

The three most important cognitive objectives for crossing disciplinary boundaries that have influenced the development of the sciences in the 20th century are (1) the ideal of a unity of all sciences and other disciplines, (2) solving problems in basic research by innovation, and (3) responding to the knowledge demands of the knowledge society. These objectives can be combined and they may cross-fertilise each other (Pohl et al., 2008).

The considered central challenges of transdisciplinarity are:

- Crossing boundaries: disciplines, academia-society, individuals-companies, forms of generating knowledge, forms of comunicating
- '*Not for society, but with society*' (Scholz at INIT, 2012)
- Integration: considered the main cognitive challenge of transdisciplinary process

5.2 From discipline to transdisciplinarity

Brief explanations of the different concepts are outlined below.

5.2.1 Disciplinarity

The early Universities[3], started with Faculties of Medicine, Philosophy, Theology and Law. It was around these four areas that the totality of knowledge was contained, with versatile academics. As Faculties became more and more specialized, disciplines and sub-disciplines arose and multiplied. The departmentalization of disciplines consolidated itself at the end of the XIX Century, maintaning disciplinary autonomies, for the competition of research funds, and for the consolidation of academic prestige. Disciplinarity is about mono-discipline, which represents specialization in isolation ((Max-Neef, 2005).

Defined academic research methods and objects of study constitute disciplines. They include frames of reference, methodological approaches, topics, theoretical canons and technologies. Disciplines can also be seen as 'sub cultures' with their own language, concepts, tools and credentialed practitioners (Petts et al, 2008).

[3] Such as Salerno, Bologna, Oxford and Cambridge

5.2.2 Multidisciplinarity

A person may have studied, simultaneously or in sequence, more than one area of knowledge, without making any connections between them. Members of multidisciplinary teams of researchers or technicians carry out their analyses separately, as seen from the perspective of their individual disciplines, the final result being a series of reports pasted together, without any integrating synthesis (Max-Neef, 2005). Different disciplines come together in a specific context (typically to deal with a real world problem) but with each group working primarily in its own framings and methods. This is a working approach that juxtaposes rather than combines separate disciplinary perspectives, adding a breadth of knowledge, information and methods. Work is done independently following separate perspectives (Klein, 2007).

5.2.3 Pluridisciplinarity

Pluridisciplinarity implies cooperation between disciplines, without coordination. It normally happens between compatible areas of knowledge, on a common hierarchical level. Examples could be the combination of physics, chemistry and geology, or history, sociology and language. The study of each one of them reinforces the understanding of the others (Max-Neef, 2005).

5.2.4 Interdisciplinarity and transdisciplinarity

The term 'interdisciplinary research' refers to a range of approaches from the simple communication of ideas to mutual integration of organising concepts, methodology, epistemology, etc. (OECD, 1972 cited in Klein 2007: 37). Rather than disciplines operating in parallel, it involves a synthesis of knowledge, in which understandings change in response to the perspectives of others. The aim is to seek coherence between the knowledges produced by different disciplines (Petts et al, 2008).

Max Neef (2005) explains interdisciplinarity and transdisciplinarity as different kinds of relationships between different hierarchical levels of groups of disciplines, which he calls the '*hierarchy disciplinarity pyramid*' (Fig. 1)

Interdisciplinarity is organized at two hierarchical levels. It thus connotes coordination of a lower level from a higher one. '... *A sense of purpose is introduced when the common axiomatics of a group of related disciplines is defined at the next higher hierarchical level*' (Schulz, cited in Max-Neef, 2005). Disciplines as mathematics, physics, chemistry, geology, ecology, sociology, genetics, economics (in addition to others) can be considered as the base of a pyramid, identifiable as *the empirical level*. Immediately above is another group of disciplines that constitute the *pragmatic level* (engineering, architecture, agriculture, medicine, etc). The third is the *normative level*, including disciplines such as planning, politics, design of social systems, environmental design, etc. Finally, the top of the pyramid corresponds to a *value level*, and is occupied by ethics, philosophy, and theology. Thus a hierarchical image is defined in which the purpose of each level is defined by the next higher one (see section: *Knowledge generation*).

Transdisciplinarity is the result of coordination between all hierarchical levels. The disciplines at the base of the pyramid describe the world as it is. This level asks and answers the question *what exists?* And the organizing language of this level is logics. The next level is composed mainly of technological disciplines. This level asks and answers the question *what are we capable of doing*? with the knowledge gained from the empirical level. The organizing language of this level is cibernetics that emphasizes only the mechanical properties of nature and society. The normative level asks and answers the question *what is it we want to do?* The organizing language of this level is planning. The value level asks and answers *what should we do? how should we do what we want to do?* The organizing language of this level that goes beyond the present and the immediate should be some kind of deep ecology (Schulz, cited in Max-Neef, 2005).

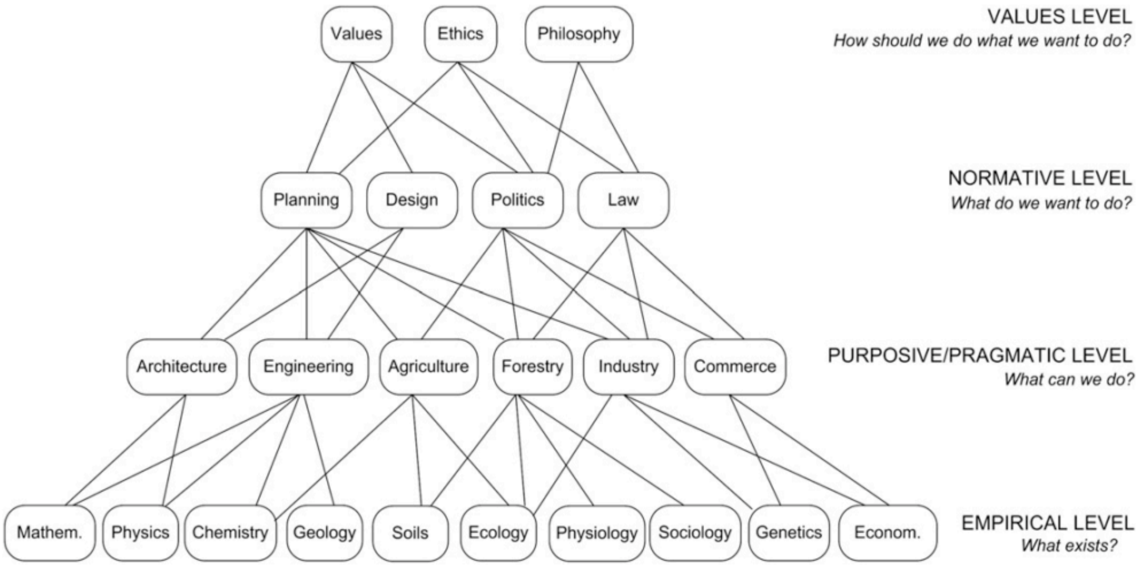

Fig. 1. The pyramid of transdisciplinarity (Max-Neef, 2005, p. 9)

5.2.5 Differences between multi-, inter- and transdisciplinarity

Multidisciplinarity and interdisciplinarity do not break with disciplinary thinking (Fig. 2). In the case of multidisciplinarity, the aim is mainly the juxtaposition of theoretical models belonging to different disciplines. Disciplines are considered as being complementary in the process of understanding phenomena. The point is not to take into account the entire model, but only part of each model, which can be the object of bilateral consensus, in order to maintain coherence. The advantage of this approach is that it highlights the different dimensions of the studied object and respects the plurality of points of view. These aspects of multidisciplinarity are most visible in colloquia.

Interdisciplinarity differs from multidisciplinarity in that it constructs a common model for the disciplines involved, based on a process of dialogue between disciplines. For this reason, interdisciplinarity is often implemented within the same disciplinary field and its purpose is to create synthesis. However, the second important aspect of interdisciplinarity lies in the practice of transfers, either of models or of tools (such as mathematics, statistics), from one discipline to another. In any case, however, regardless of the form it takes, interdisciplinarity, like multidisciplinarity, avoids paradoxes and having to solve them. Both interdisciplinarity and multidisciplinarity approaches are fragmented dealing with disciplinary thinking.

Transdisciplinarity breaks away with this type of thinking in a significant way, since the objective is to preserve the different realities and to confront them. Thus, transdisciplinarity is based on a controlled conflict generated by paradoxes. The objective is no longer the search for consensus but the search for articulations. The aim is thus to avoid reproducing fragmentary models typical of disciplinary thinking (Ramadier, 2004).

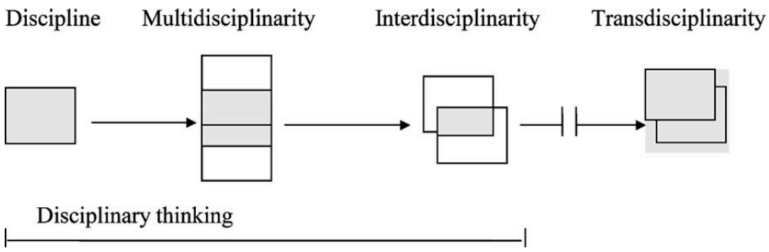

Fig. 2. From discipline to transdisciplinarity (Ramadier, 2004)

5.3 *Historical perspective of the production of knowledge: unity, science and life-world*

In Greek antiquity the idea evolved that science is basically a cognitive faculty for explaining the development of natural things, based on principles inherent to them, that humans are capable to be aware of through "contemplation"[4] (as Aristotle claimed). This kind of scientific knowledge (epistême) is of no use for day-to-day living. To lead their life, humans need skills to act (praxis) and to produce (poiêsis), and they need prudence (phronêsis) to deliberate about things that allow choice. **So, science born detached from practical life or the life-world, namely ideal scientific knowledge is dissociated from the various aspects of practical knowledge** (Klein, 2008).

This ancient ideal is still influential today, although the concept of science and the relationship between science and the life-world has changed. The emergence of transdisciplinary orientations in the knowledge society at the end of the 20th century is the most recent step in reshaping the concept of science and the distinctions between science and the life-world (Klein, 2008).

On the other hand, the idea of the unity of the knowledge has been longer pursued. In the Middle Ages, there were universities divided into "faculties", which all answered to the School of Theology. This responded to the wish to create a synthesis between the different branches of knowledge to reach its unity (Ramadier, 2004), with an ideological aim. In the 18th century, the *Enlightenment* extended knowledge to society (cities, salons, academies, press, etc.), to enrich culture with scientific discoveries. The wish to create relationships between different disciplines, on the contrary, became a pragmatic aim, that led to the division of scientific activity into more or less independent disciplines and the emergence of specialists. Thus, regardless of whether the wish to establish relationships between different scientific disciplines is due to pragmatic or ideological reasons, the construction of pan-disciplinary [5] knowledge is mainly motivated by the idea that there is only one reality (Ramadier, T., 2004). The thought in the industrial period assumed that this unity could be synthetist from analizing the preserved form of disciplinary thinking. However, nowadays, disciplines and ever more sub-disciplines seem to make it difficult to consider an object of study as being indivisible and pertaining to only one reality. As a result, synthesis is no longer able to

[4] "Contemplation" is the meaning of the Greek term "theoria".
[5] "Pan", Greek sufix that means "implying the union of all branches of a group".

integrate what disciplinary analysis has previously separated (Ramadier, 2004). Cross-disciplinary approaches (multi-, inter-) consider all the overlapping aspects of different disciplinary approaches, to deal with.

The dissociation of the natural sciences from philosophy started in the modern period (the late 16th Century) and continued into the 19th century by the establishment of the humanities and the social sciences. Science is conceived dissociating philosophy from natural sciences, which processes are explained by general principles on the scientific knowledge. An example is the Newtonian science, which reduces the plurality of phenomena in nature to some basic laws, closely related to practical issues, as production of goods. Francis Bacon (1561–1626) also Though that scientific collaboration is of upmost importance for scientific progress, and he shows little interested in benefiting society (Alvargonzalez, 2011).

In the 19th century, modern science was criticised as a model for all of science. In the second half of the century and in the early 20th century, influenced by the serious problems of rural and industrial working classes, the constitution of the so-called 'human sciences' (sociology, economics, psychology, cultural anthropology…) was a confirmation of the plurality of the sciences, and brought about the discussion of a new issue: the problem of the division of knowledge into 'two cultures' (using formula of C. P. Snow) (Alvargonzalez, 2011), the cultures of science and humanities, as separate specialised disciplines in universities (Klein, 2008).

In this context a new rationality appears. The Chicago School of Sociology in USA, Karl Marx and Max Weber[6] in Europe and others, bring "Human Ecology" and "Social Action". Max Weber related research in social sciences with knowledge demands for societal problem solving. Jürgen Habermas conception of communicative rationality[7] providing foundations for models of dialogue is broadly referred to in transdisciplinary research. This typology of the sciences and their rationality replaces the antique distinction beetwen science (episteme) and knowledge of the life-world (poiêsis, praxis and phronêsis), by relating science with different types of interests: production, action and deliberation (Klein, 2008).

By the beginning of the 1940´s, the System theory that syudies the abstract organisation of phenomena, independent of their substance, type, or spatial or temporal scale of existence had been developed in many fields[8]. The huge importance for integrative approaches (inter-, trans-) is related to the generation of the idea of an abstract structural unity of scientific knowledge (Alvargonzález, 2011), against the background of fragmentation of the sciences. Also the last is becoming recognized as a major risk for society, because specialisation prevents the recognition of possible negative side effects in research, education and social institutions in general (Horlick-Jones & Sime, 2004).

Ramadier rises that the notion of unity becomes obsolete in transdisciplinary process, as unity is a state and not a process. For him, the main role of transdisciplinarity lies in the dynamics of the articulation from disciplinary knowledge. As the "whole" is more than the sum of its parts, this is made up of all the articulations between the levels of

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[6] Karl Marx (1818–1883), Max Weber (1864–1920).

[7] Jürgen Habermas argues for three types of scientific rationality related to specific standards in research (Habermas, J., 1987): (1) instrumental rationality of the empirical sciences and their standards of experimental testing, (2) rationality of the historical sciences, which concerns the role of knowledge in creating meaning for life and personal identity in societal contexts, and (3) communicative rationality as communicative action, which are about societal transformations.

[8] Systems theory investigates both the principles and the mathematical models used to describe them of phenomena. Was proposed by Ludwig von Bertalanffy (1901–1972) in biology; and developed by Norbert Wiener (1894–1964) in cybernetics; by John von Neumann (1903–1957) in game theory; by Claude Elwood Shannon (1916–2001) in information theory; and by Niklas Luhmann (1927–1998) in sociology, among others.

reality established by disciplinary knowledge. Articulation is what enables coherence within paradoxes, and not unity, as well as putting together the knowledge of each discipline does not mean adopting a transdisciplinary attitude (Ramadier, 2004).

5.4 Knowledge Generation

Many scientists have been arguing during last few decades, that our relation with a complex world and a complex nature requires complex thought (Max Neef, 2005). Considering its increasing complexity Edgar Morin proposes a radical reform of our organization of knowledge, developing a kind of recursive thinking, capable of establishing feedback loops in terms of concepts such as whole/part, order/disorder, observer/observed, system/ecosystem, in such a way that they remain simulateously complementary and antagonistic (Morin, 1992). The bottom principle is not to separate the opposing poles from the many di-polar relations that characterize the behaviour of nature and of social life. **It is normal separation, in rational thinking with its linear logic, but actually artificial, since neither nature nor the human society does function in terms of mono-polar relations**. Our insistence in artificially and ingeniously simplifying our knowledge about nature and human relations, is the force behind the increasing disfunctions we are provoking in the systemic interrelations of both eco-systems and the social fabric (Max Neef, 2005).

Instead of the huge growth of knowledge production that linear logic and reductionism have contributed to, Max Neef says that '*If I were asked to define our times, in few words, I would say that we have reached a point in our evolution as human beings, in which we know very much, but understand very little*'. Knowing is not the same as understanding. While within the realm of knowledge, it makes sense that I (Subject) pose a problem and look for its solution (Object), in the realm of understanding no problems exist, but just transformations that indisolubly integrate Subject and Object (Max Neef, 2005). Perhaps the conclusion is that knowing and understanding, belong to different levels of reality[9] (Nicolescu, 2000) (see section 5.5.2). Understanding, more linked to intuition, rules out both method and causality, which are both constructing formal knowledge. Hence, being in different levels of reality, understanding may solve the contradictions that arise in knowledge (Max Neef, 2005).

From Jantsch it was suggested the idea that knowledge should be organized into hierarchical systems by the coordination of four levels, described in the following way: purposive (meaning values), normative (social systems design), pragmatic (physical technology, natural ecology, social ecology) and empirical (physical inanimate world, physical animate world, human psychological world). The coordination should follow horizontal principles within each level and vertical principles between levels and sub-levels. The ultimate degree of coordination they called transdisciplinarity (Hadorn et al., 2011). Max Neef (2005), based on the proposal of Jansch, raised the '*hierarchy disciplinarity pyramid*' (see Fig. 1).

Gaizulosoy and Boyle (2012)[10] relate the pyramid of transdisciplinarity with the areas of knowledge generation in the transdisciplinary research process (Fig. 3). It is argued

[9] Two different levels of reality are different if, while passing from one to the other, there is a break in the laws and a break in fundamental concepts like, for example, causality (Nicolescu, 2000)
[10] In his research of an heuristic tool developed to help individual researchers undertaking transdisciplinary projects in systematic structuring and prioritization of the literature review/reporting process.

that when the goal of transdisciplinary research is to respond to societal knowledge demands, three kinds of knowledge[11] are required (Hadorn et al., 2010; Klein, 2001):

1. Systems knowledge: knowledge of the current status, about the origins and development of problems reduces scientific uncertainty through improved understanding of the causal relations relevant to the problem (ProClim, 1997) including their interpretation in the 'life-world'
2. Target knowledge: knowledge about the system status required and/or desired to be reached, as needs for change, desired goals and better ways of acting)
3. Transformation knowledge: knowledge about the means to achieve this transformation, as technical, social, legal, cultural and other means of transforming existing ways of acting in desired directions (Hadorn et al., 2006)

These three types of knowledge require each other in order to be generated and influence one another during the research process. The systems knowledge is mainly acquired from the two bottom levels, wich provide the empirical information necessary to understand the situation. Target knowledge involves visioning for a new system status, referenced to the normative and the values levels of the pyramid. Transformation knowledge does not directly link to any of the levels of the pyramid since its structure is amorphous and generally specific to the problem being addressed, but is generated through synthesis of knowledge from all four levels of the pyramid.

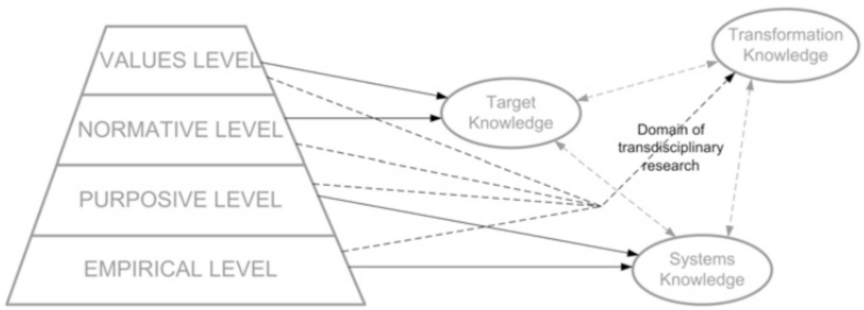

Fig. 3. Relationships between the pyramid of transdisciplinarity and the three types of knowledge of the transdisciplinary research domain where both problem framing and new knowledge generation takes place.

These three forms of knowledge remind us of Aristotle's forms of knowledge, namely: science (episteme); life-world action (praxis); production (poiêsis); and prudence (phronêsis), now transformed as goals of transdisciplinary research (Hadorn et al., 2010 in Hadorn et al., 2010). Meeting these knowledge demands requires grasping the relevant complexity of the problems, taking into account the diversity of scientific and societal views of the problems, linking abstract scientific reflection with relevant case-specific knowledge, and constituting recursively knowledge with a focus on problem solving for what is perceived to be the common good. The first step for such integration is to acknowledge, to respect and to explore the diversity of perspectives (Pohl and Hirsch Hadorn, 2007). Even more as Benessia et al. (2012) defends, hybridizing sustainability with a variety of knowledges and experiences means engaging with the inherent complexity, indeterminacy of experimentation over socio-ecological systems, promoting a fundamental epistemic and normative shift from searching what to do and to choosing how to do it.

[11] The terms were coined in 'Research on Sustainability and Global Change – Visions in Science Policy by Swiss Researchers' (ProClim, 1997), whith the definition of 'systems knowledge' as knowledge of the current status; of 'target knowledge' as knowledge about a target status; and 'transformation knowledge' as knowledge about how to make the transition from the current to the target status.

5.5 The different transdisciplinarity approaches

The upper historical perspective points to why transdisciplinarity is a fuzzy and contested concept, shaped by various lines of thinking, heterogeneous conceptions of science and approaches to research, with a variety of terminologies and definitions.

5.5.1 Earlier ideal notions of transdisciplinarity

The earlier notions predicating transdisciplinarity, being a hyper form of interdisciplinarity, had the aim to develop an overarching framework for similar problems and transform education from 'training' into 'genuine' (Klein et al., 2001).

After the first international conference on interdisciplinarity, held in France in 1970 and co-sponsored by the Organization for Economic Cooperation and Development (OECD), some participants wanted the term transdisciplinarity to be in the title of the seminar and the post-seminar book. At this time, higher education was being pressed worldwide by calls for reform. Some participants developed the concept further into two interests. Erich Jantsch did with external purpose. He proposed institution education structures based on feedback among three types of units: systems design laboratories, function oriented departments, and discipline oriented departments with a focus on interdisciplinary potential in a hierarchical goal oriented system of science, education, and innovation in purposive levels '*the essential characteristic of a transdisciplinary approach is the coordination of activities at all levels of the education/innovation system towards a common purpose*' (Jantsch, 1972: 114). Jean Piaget focused on internal dynamics of science, and recognized about this that "*It's just a dream*" (Klein, 2004).

The filosofer Joseph Kockelmans in a 1979 collection of essays on interdisciplinarity published in the USA, suggests the term '*crossdisciplinary work*' for research which 'is primarily concerned with finding a reasonable solution for the problems that are so investigated, whereas transdisciplinary work is concerned primarily with the development of an overarching framework from which the selected problems and other similar problems should be approached' (Kockelmans, 1979). He situated transdisciplinarity in the philosophical and educational dimensions of sciences, because he aligned the concept with the work of a group of scientists trying to systematically determining how negative effects of specialisation can be overcome to make both education and research more socially relevant (Klein, 2004). At this time in the USA, 'transdisciplinary science' connotation arose in the field of to cancer studies and well-being (Hadorn et al., 2010).

5.5.2 Towards society and real life problem solving

By the end of the last century, two currents of definition gained wide attention. Both were drawn notions of transdisciplinarity as a methodology.

On the one hand, there is the need to facilitate a broad scientific and cultural dialogue, informed by the new complexity view (Klein, 2004). Changes are originated at the first World Congress on transdisciplinarity in Portugal, 1994. The participants endorsed the Charter of Transdisciplinarity. In 1987 Basarab Nicolescu and fellow members of

CIRET[12] (the Centre International de Recherches et Etudes Transdisciplinaires), began developing a broad-based scientific and cultural approach capable of facilitating long-term dialogue between specialists and educators, from the worldview of complexity in science. Nicolescu identified three pillars of transdisciplinarity[13]:

- Complexity: relativity (not reductional), transcultural, transnational, and encompasses ethics, spirituality, and creativity
- Multiple levels of reality: multidimensionality against to the one-dimensional reality of classical thought
- The logic of the included middle: capable of describing coherence among different levels of reality, inducing an open structure of unity

Nicolescu calls it the science and art of discovering bridges between different areas of knowledge and different beings. Edgar Morin, also a member of CIRET, adds that knowledge of complexity also demands a new dialogue that bridges humanistic and scientific cultures[14] and consequently a new reform of the education (Klein, 2004). This type of transdisciplinarity requires a personal commitment "challenging that the dignity of the human being is of both planetary and cosmic dimensions" (Freitas et al. 1994, Nicolescu, 2000 cited by Scholz at Leuphana Summit, 2012). It means that an openess to different epistemic cultures, experiential contexts, ethics, spirituality, are needed.

On the other hand, there is the need to deal with real-life problems. Jürgen Mittelstraß uses the term in defining '*transdisciplinarity as a form of research that transcends disciplinary boundaries to address and solve problems related to the life-world*' (Mittelstrass, 1992 cited in: Hadorn, G.H., et al., 2008: 20). Scholz refers to as: '*Science becomes transdisciplinarity if it reflects on real life problems'* (Mittelstrass, 1996, cited by Scholz at Leuphana Summit, 2012).

Silvio Funtowicz and Jerome Ravetz deal with the concept of post-normal science, arguing that science must engage in dialogue with all those who have a stake in a decision of high uncertainty (Funtowicz and Ravetz, 1993). They claimed that '*The objective of scientific endeavor in this new context may well be to enhance the process of the social resolution of the problem, including participation and mutual learning among stakeholders, rather than a definitive 'solution' or technological implementation. This is an important change in the relation between the problem identification and the prospects of science-based solutions*' (Funtowicz et al., 1998, in: Hadorn, 2006). This post-modern type of transdisciplinarity claims that approaching truth from only science in complex contextualized settings, becomes obsolete: science just becomes one voice and vote. It's imperative the management of irreducible uncertainties in knowledge and in ethics, and the recognition of different legitimate perspectives and ways of knowing (Funtowicz & Ravetz, 1993)

Michael Gibbons and Helga Nowotny claim that a new form of knowledge production has emerged, the so-called mode-2 (Gibbons et al. 1994; Nowotny et al. 2001). Mode-2 knowledge production refers to problem-solving processes that imply the activity of multiple drivers and skills, so that the intellectual endeavour and solutions arise within disciplines, transgressing institutional boundaries. Nowotny characterizes mode-1 science as having a clear separation between science and society, while in mode-2

[12] CIRET is a virtual meeting space for specialists from all domains. It publishes an electronic journal, results of UNESCO-sponsored international colloquia (including the first world congress on transdisciplinarityin Portugal in 1994 and the 1997 congress on the transdisciplinary evolution of the university in Locarno, Switzerland), and reports on projects around the world http://perso.club-internet.fr/nicol/ciret/

[13] In the Manifesto (1996), and the essay "New Vision of the World" at http://perso.club-internet.fr/nicol/ciret/.

[14] E. Morin, Réforme de pensé congress Quelle universite, transdisciplinarité, reforme de l'universite pour demain? Vers une evolution transdisciplinaire de l'universite Locarno. 30 April–2 May1997. CIRET-UNESCO: Evolution transdisciplinaire de l'universite Bulletin Interactif du CIRET, 9–10 (1997) at http://perso.club-internet.fr/nicol/ciret/.

boundaries between science and society are transgressed. Mode-2 knowledge has features such as transdisciplinarity, heterogeneity, reflectivity, social accountability, and context- and user-dependency (Alvarezgonzález, 2011).

At the International Transdisciplinarity Conference in Zurich in the year 2000, is featured a latest transdisciplinary approach on real-world problem solving, highlighting the convergence of transdisciplinarity, complexity, and trans-sectorality in a unique set of problems that do not emanate from within science. As result it is defined Zurich 2000 transdisciplinarity as (Häberli et al. 2001):

> *'Transdisciplinarity is a new form of learning and problem solving involving cooperation among diferents parts of society. Transdisciplinarity research starts from tangible, real-word problems. Solutions are devised in collaboration with multiple stakeholders. A practice-oriented approach, transdisciplinarity, is not confined to a close circle of scientific experts, profesional journals and academic departments where knowledge is produced. Ideally, everyone who has something to say about a particular problem and is willing to participate, can play a role. Through mutual learning, the knowledge of multiple participants is enhanced, including local knowledge, scientific knowledge and the knowledges of industries, businesses, and NGO's. The sum of this knowledge will be greater than the knowledge of any single partner. In the process the bias of each perspective will also be minimized.'*

Based on this, transdisciplinarity is a reflexive, integrative, cooperative, method-driven scientific principle aiming at (Lang et al., 2012):

a) The **solution or transition of societal relevant problems** and concurrently of related scientific problems, by differentiating knowledge from various scientific and societal bodies of knowledge.
b) Enabling **mutual learning processes** among researchers from different disciplines (from within academia and from other research institutions), as well as actors from outside academia, on equal footing; and
c) Aiming at **creating and integrating knowledge** that is solution-oriented, socially robust[15], and transferable to both the scientific and societal practice, also considering that transdisciplinarity can serve different functions, including capacity building and legitimization (Scholz 2011).

5.5.3 The 'Southern' perspective

In this perspective, principles of integrating research and social change similar to action research have been developed, a radical concept of science in which theory and practice should be mutually beneficial. Near to this, what today is called 'southern version of transdisciplinarity' is closely related to the impacts of the writings of the Brazilian authors Paulo Freire and Leonardo Boff, who in the framework of theory of liberation published a specific methodology for working with the people (Boff, 1986 cited in Hadorn, 2006). The pedagogy of Freire understands literacy education not only in terms of reading the word, but also reading the world. This means that the creation of a critical consciousness becomes an important content of development. Freire develops the practical educational implications of Habermas' conception of communicative action (Morrow and Torres, 2002 cited in Hadorn, 2006). A basic common element is their shared confidence in 'dialogical and reflexive learning'. These changes have been taking place during the past thirty years in the design of research projects in development cooperation. Where, at the beginning, researchers defined the

[15] See Gibbons, 1999.

problems and the solution, now, the affected population's participation is supported in the research process. New approaches and methods, such as rapid rural appraisal (RRA) and participatory rural appraisal (PRA), are being developed to integrate people knowledge.

In the discourse of human rights accountability, new modes of knowledge, discourse, and institutional frameworks were needed across all sectors in both the North and the South. Researchers emphasize that scientific concepts and methods cannot be imposed on indigenous knowledge and complexity. Biophysical and human dimensions must be integrated spatially and temporally in a holistic approach, if it's necessary to identify ways of improving ecosystems and human welfare (Jabbar, 2001; Fry, 2001). Also, social and health scientists began to produce conceptual analyses and empirical findings in the area of transdisciplinary health research, at 1990s, spurred primarily by some innovative work at the University of Newcastle (Australia). Article 14 of the Charter of Transdisciplinarity[16], is relevant here: "*Rigor, openness, and tolerance are the fundamental characteristics of the transdisciplinary attitude and visión (…)*".

5.6 Transdisciplinarity and Sustainability

The concept of transdisciplinarity has become aligned with sustainability in the last discourse of problem solving (Klein, J.T. Unity of Knowledge and Transdisciplinary, OCDE). The United Nations Conference on Environment and Development in Rio de Janeiro 1992, had the commitment of the statesmen from most nations to sustainable development as a way to conceive the common good as the basic principle of public legislation in a complex world. With sustainability as its normative model, science and scientific activity is demanded to be an 'agent of change', adopting problem-solving approach and innovation for society, not only a resource for integrating scientific knowledge (Krohn and Van den Daele, 1998 cited in Leuphana Summit, 2012).

Sustainability problems are widely recognized as wicked problems[17] (Norton 2005; Raffaelle et al. 2010, cited in Seager et al. 2011; Brundiers and Wiek, 2010), beyond the scope of normal, current, industrial-age engineering science. Lots of authors agree that the scientific expertise required to deal with this is in need of reform. Two major views regarding this posible reform have been observed (Seager et al. 2011). A more conservative view, suggests that science's ethical, educational, and procedural cultures do not require significant transformation, so science can meet the challenges of sustainability by inventing sustainable technologies that drive innovation. It has been caracterized as business-as-usual and systems engineering approaches (Seager et al., 2011). From sustainability concerns, they are handicapped due to knowledge resides more and more in narrow specializations (Wiek et al. 2007), leading to new capabilities even though regardless of broader contextual questions.

A more proactive view, so-called sustainable engineering science, proposes shifting orientation towards more integrative approaches to science, education, and technology that (Seager et al., 2011): (1) include *macroethics*[18] beyond the usual bounds of professional responsible conduct, (2) approaching risk-based design and management

[16] The Charter of Transdisciplinarity was signed at First World Congress of Transdisciplinarity, Convento da Arrabida, Portugal, November 2– 6, 1994, Article 14. Available at: nicol.club.fr/ciret/english/charten.htm.
[17] Conceptualization attributable to Norton (2005): sustainability problems exhibit typically ten characteristics reduceable to five, also constitutive of wicked problems: difficulties in problem formulation, multiple but incompatible solutions, open-ended timeframes, novelty (or uniqueness), and competing value systems or objectives. Similar concepts were developed earlier by Rittell and Webber 1973, Funtowicz and Ravetz (1993) and Dovers (1996) (Seager et al., 2011).
[18] Ethical considerations must be considered at the scale of the collective.

to consider anticipation, adaptability, and *resilience* (3) cultivate *interactional expertise* to facilitate cross-disciplinary exchange.

Macroethics looks at these moral dilemmas that are not traceable and result from the complex and dynamic interaction among many actors (individuals, organizations, professions, industies) (Fig. 4). Consequently, they cannot be resolved without deliberation and collective action harder (Seager et al., 2011).

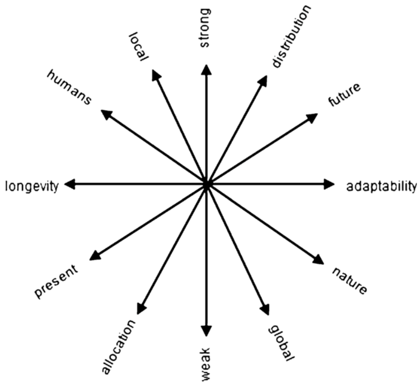

Fig. 4. Sustainability sextant: macro-ethical tool that illustrates several points of ethical tension that define different interpretations of sustainability. In formulating any problem within the domain of sustainability, scientists must confront each of these axes on a multi-dimensional Sustainability Sextant. Each dimension is interrelated in the sense that some perspectives suggest or are more consistent with others. Nonetheless, the purpose of the Sextant is to guide individuals from their own points of view to those that may be foreign to them (Seager, Selinger, & Wiek, 2011).

On the other hand, taking into account that wicked problems should not be thought of as problems to be solved, but conditions to be governed, designing for resilience, will comprise adaptive strategies based on the ability of a system to respond to stressors without losing basic functionality or structure (Holling 1996). So, the sustainability engineering scientist must acquire a macroethical awareness, the deliberation skills necessary to work through macro-ethical issues in concert with others and an anticipatory competence, to be capable of imagining possibilities (as opposed to estimating probabilities) and understanding the potential consequences of adaptive interventions and cultivate interactional expertise (Wiek et al. 2011).

Sustainability research and transdisciplinary research strongly overlap and is considered interchangeably (Kates et al., 2001). Also, transdisciplinary aspects of research for sustainability encompass social sciences and humanities as well as the participation of societal actors. When entering transdisciplinarity, engineering researchers enter unfamiliar grounds for scientific knowledge production (Hadorn et al., 2006).

Transdisciplinarity research is considered also, a form of action research. Participation and learning circles have to start from the beginning, where the scientist as an "observer of the common learning process" (Häberli, R. 2001). The concept of linking knowledge to action for sustainability (Kates et al., 2001) has been reiterated during the last decade (Komiyama and Takeuchi, 2006, van Kerkhoff and Lebel, 2006 cited in Wiek et al., 2012). Yet too many scholars still believe that this link will miraculously emerge, it obviously requires a very different type of research and education to generate knowledge that matters to people's decisions and engages in arenas where power dominates knowledge; and education that enables students to be visionary, creative, and rigorous in developing solutions and that leaves the protected space of the classroom to confront the dynamics and contradictions of the real world (Sarewitz et al. 2010; Wiek et al. 2011).

Transdisciplinarity raises the question of not only problem solution but problem choice (Klein, 2004; Scholz at Leuphana Summit 2012). However in order to meet the knowledge demands for sustainable development, diferent approaches are needed depending on the kind of problems to be solved (Funtowicz et al., 1998 in Hirsch Hadorn et al., 2006); Seager et al., 2011). Since its inception, sustainability science has evolved to become a problem- and solution-oriented field inspired by the post-normal science philosophy that adopts transdisciplinary and participatory research practices (Leeuw et al., 2012, Wiek et al. 2012; Lang et al. 2012). This evolution has bifurcated the field into a descriptive–analytical stream and a transformational stream or, in other words, in '*traditional disciplinary-based science for sustainability and the transdisciplinary science of sustainability*' (Spangenberg, 2011: 275). In short, sustainability science in its transformational mode seeks broad transdisciplinary participation throughout research and practice focused on solving sustainability problems. Transdisciplinarity, as active collaboration with various stakeholders throughout society must form another critical component of sustainability science (Yarime, 2012).

5.7 Transdisciplinarity and Higher Education

While research and education slowly recognize the importance of shifting their efforts to sustainability challenges and their root causes (Jerneck et al. 2011; Spangenberg 2011; Wiek et al. 2011 cited in Wiek et al., 2012), sustainability scientists lack experience and expertise in contributing to feasible and effective solution options (Wiek et al., 2012). Principles for higher education have to be developed that are focused on the problem-oriented transdisciplinary approach to provide future researchers with the relevant knowledge and skills (Bergmann et al., 2010 in: Jahn et al., 2012). Moreover knowledge of complexity, Edgar Morin exhorts, also demands a new dialogue that bridges humanistic and scientific cultures (Klein, 2004).

Currently, academia is poorly positioned to address sustainability problems because of anachronistic pedagogy, mismatched incentives, insufficient expertise, lack of personal commitment, familiar and comfortable patterns for scholars, and isolated products and communication (Leeuw et al., 2012; Brundiers et al. 2010; Yarime et al. 2012). Existing education and research training programs are ill-equipped to prepare scientists and engineers to operate effectively in a wicked problems milieu. Advancing sustainable engineering science requires to create new long-term, participatory, solution-oriented projects programs as platforms for the next generation of sustainability scientists and engineers to recognize and engage with the macro-ethical, adaptive, and cross-disciplinary challenges embedded in the cutting-edge problems and approaches in the field their professional issues (Seager et al., 2011). As new programs evolve, they can be the proving ground for new pedagogies, incentives, and transdisciplinary collaboration within and beyond the academy.

But education always seems to go after the events. The implementation of academic concepts and methodologies in the practice of sustainability science programs, has not yet been examined in detail, while they have been discussed theoretically in the literature (Yarime et al., 2012). It is true that the business of education has traditionally been, just the transmission of knowledge, but the future will be more dynamic. The time when young people acquire profesional training up to the age of about 20 or 25, then stay on this activvity to the age of retirement, has passed. Therefore, training in how to work in teams with experts from many different fields, how to learn and adapt quickly and permananntly to ever-changing situations are new imperatives for preparing new professionals (Häberli, R. in Thompson Klein, J. 2001, pg. 17). It is also argued that the transience terms of most academic projects do not match the long-term relationship and capacity building required for meaningful participatory engagement and transformational change (Benessia et al. 2012). In the same way, as editors of Handbook of Transdisciplinary Research[19] noticed, there is a disconnection between local efforts and the abundant information and insights that have emerged in the task: 'What has been learned on the job', they lamented, 'is seldom passed on to others for capacity building' (Hadorn et al., 2010). So, the lack of education might be explainable.

Nevertheless, in spite of any old pattern, the advocation of operationalizing the goals of the field, developing the necessary competencies, and seeking novel partnerships between society and the academy will position academic institutions to make a bigger impact on the transition to sustainability (Leeuw et al., 2012).

5.7.1 Transdisciplinary Skills

Julie Thompson Klein, who has most revised transdisciplinarity education programs over the world, collected three main statements about the skills needed for transdisciplinary work (Klein, J., in Hadorn et al., 2010). The first is the 'quadrangulation' of: disciplinary *depth*, multidisciplinary *breadth*, interdisciplinary *integration*, and transdisciplinary *competencies*. Disciplines provide essential knowledge and remain in transdisciplinary work. Breadth of exposure to multiple disciplines, precise the capacity of articulate specific knowledge and experience gained in the own disciplines. ID precise of the ability to work with pertinent information, to contrast approaches, to clarify differences, and to generate a synthesis, integrative framework. Cultivate transdisciplinarity competencies is related to the last two statements. The second statement is the reconceptualisation of education as a dynamic dialogue of content (principles, approaches, methods, analysis, strategies) and process (how to organize, participate and communicate). The third is the interwined relationship of transdisciplinary competencies.

Derry and Fischer (Derry & Fischer, 2006) conceptualised a set of overlapping categories of transdisciplinarity competences/skills for graduate STEM (science, technology, engineering, and mathematics) education (applicable beyond STEM domain):
- The ability of productive and reflective participation (understanding of work communities, effective communication)
- Mindset for lifelong learning (critical thinking, on demand and self directed learning);
- The ability of innovative sociotechnical environments, fluent digital media use
- The ability to teach and learn in new knowledge building communities
- Willingness to become an engaged citizen for real world needs

Pohl, van Kerkhoff, Hirsch Hadorn, and Bammer (Klein, 2001) designate some skills needed to lead transdisciplinary and integrative projects:
- Ability to adequately scope issues to apply an integrative approach
- Ability to apply integrative methods and processes (modeling and group facilitation)
- Ability to draw on strengths of different research epistemologies, tailoring them to a common task

[19] The Handbook of Transdisciplinarity Research emaned from 'td-net' network advisory board, at their first meeting in 2003, but it was edited three years after.

- Understanding of policy, practice and product development
- Ability to foster research collaboration

In both the underlying theme is cognitive flexibility, manifested in a willingness to see beyond one's own discipline, and to the integration of knowledge. Of course, authors warn that nobody will be expert in all areas and other members and teams are needed to fill skill gaps. Developing a larger framework for skills and allowing concentration on a subset of them can also provide the core of undergraduate and graduate curricula.

Studies carried out at Belgian and Catalan universities (Lambrechts, Mulà, Ceulemans, Molderez, & Gaeremynck, 2012; Cortés et al., 2010) show that competences for SD are more often linked with ethical and moral attitudes, and less frequently with system orientation, future orientation, and action skills, that are related to transdisciplinary skills. Competences for SD indicate what needs to be trained and studied, so the absence of some key competences for SD requires a reorientation of existing, or integration of new ones. Some competences related to system orientation are present in the competence schemes, especially those stressing interdisciplinary cooperation, but still the competences for system orientation are too fragmented. It is clear that elements of system orientation and future orientation have to be stressed, as these competences are lacking in the competence schemes.

In a Delphi study, selected experts from Europe (Germany, Great Britain) and Latin America (Chile, Ecuador, Mexico) defined '*sustainability key competencies*'. The results identified twelve key competencies as crucial for sustainable development (most featured was those for systemic thinking, anticipatory thinking and critical thinking). While the European experts attach relatively more importance to the competency for empathy and change of perspective, the Latin-American ones indicate a relatively higher relevance for the competencies for cooperation in (heterogeneous) groups and participation (Rieckmann, 2012).

Wiek et al. (2010) reviewed different sets of competencies in sustainability (Elder 2008; Fien 2002; Grunwald 2004; Sterling 2004; Wals and Jickling 2002 cited in Wiek et al., 2010), and grouped them into four categories: problem-oriented and conceptual knowledge, methodological knowledge, ability to "link knowledge to action", and interpersonal and collaborative skills.

5.7.2 Different frameworks

Transdisciplinary education appears in many contexts, widening its conceptualization. Starting with older disciplines such as philosophy that needs to make epistemological reflections on all forms of knowledge, other disciplines and study fields such as women rights, risk and ecology, has had the need to override disciplines. At the end of last century, The ´transdisciplinary science´ connotation appeared in the USA, as a form of 'transcendent interdisciplinary research' that fosters systematic theoretical frameworks for defining and analysing social, economic, political, environmental, and institutional factors in the human health ambit (Hadorn et al., 2010).

As a way of systematization, in 2002 academics from Europe, Latin America, and South Africa created the International University Reforms Observatory (ORUS), a network to promote discussions of university reform with a transdisciplinary and complex perspective being advanced in local National Reforms Observatories, in the UNESCO framework. Also in France, the CIRET develops a new universality of thought and type of education informed by the worldview of complexity in science and based on the four pillars of learning[20]. CIRET-UNESCO[21] recommended devoting 10% of discipline teaching time to transdisciplinarity, an itinerant UNESCO Chair to organise lectures involving the entire community with transdisciplinarity doctoral theses and the support of an international Internet site, and courses at all levels to make students aware of transdisciplinarity. The most complex challenge, Basarab Nicolescu stresses, is the teaching of teachers and developing appropriate pedagogies.

The new connotation focused on trans-sector transdisciplinary problem solving also lead to new models of education. Yet in 1982, OECD[22] announced that universities has to increase exchanges whith society to reach its social mission. Constanza (1990) proposed making transdisciplinary problem solving the primary function of academics, the creation of permanent structures, programmes or fields ('meta-disciplines'). Finally the European and North–South partnership for sustainability is the last contribution, with a distinguishing feature of the transdisciplinary discourse: complex problems and wider range stakeholder participation (Thompson Klein at Hadorn et al., 2010).

5.7.3 Transdisciplinary education iniciatives

As there is no systematic compilation of models and practices (Thompson Klein at Hadorn et al., 2010), some iniciatives and practices are collected in networks websites, publications from conferences, books. Here are some examples:

[CIRET's website]
→ Innovative experiences cited at Locarno Conference, at: British Open University, Academy of Architecture of Ticino, the American Renaissance in Science Education, University of Basel, Observatoire pour l'Etude de l'Université du Futur (collaboration Ecole Polytechnique Fédérale of Lausanne), Maison des Cultures du Monde.

→ Transdisciplinarity PhD thesis and programmes: Transdisciplinary Ph.D. Programs, at Texas Tech University and Stellenbosch University, South Africa; Course "Transdisciplinarity" at Doctoral school "European Paradigm", Babes-Bolyai University of Cluj-Napoca, Romania.

→ Practice of Transdisciplinarity: projects, courses, activities, experiences. Highlighting: Prevention through Design (PtD) Workshop at Texas Tech University (Atila Ertas); Art and Sustainable Enterprise beetwen International Chair on Art and Sustainable Enterprise at ICN Business School, Nancy, France and David O'Brien Centre of Sustainable Enterprise, John Molson School of Business, Concordia University, Montreal (Paul Shrivastava); First-year course of Faculty of Education: Society, Science and Culture, Education Research Transdisciplinary Group (GRET) Faculty of Education, Universitat Autònoma de Barcelona (Jaume Barrera).

[Bulletin Interactif du CIRET, num. 18]
→ Experiences in Europe, Brazil, Mozambique and Romania. University of São Paulo's Centro de Educação Transdisciplinar (CETRANS) has fostered curriculum, research, study sessions, and an educating educators project.

[Interdisciplinary and Transdisciplinary Landscape Studies, book from a seminar at Alterra GreenWorld Research in Wageningen, Netherlands, 2002 (Ute Bohnsack, University of Wageningen)]

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[20] Jacques Delors articulated at UNESCO's International Commission on Education for the 21st century, the four pillars of learning: learning to know, learning to do, learning to live together, and learning to be.
[21] 'Declaration and Recommendations' at the CIRET-UNESCO international congress in Locarno, Switzerland in 1997.
[22] University and the Community 130

→ MSc in Ecosystem Conservation and Landscape Management, helded jointly by universities in Ireland and the Netherlands. Students are placed in state agencies and private consultancies, doing field and project work in multiple countries.

[td-net Network for Transdisciplinary Research' website (sponsored by Swiss Academies of Arts and Sciences, emanated from International Transdisciplinary Conference, Zurich, 2000)]
→ Overview of Graduate Studies and Continuing Education in Transdisciplinarity projects in Switzerland
→ Complete list of journals and publications at Bibliography, sublinks Publications (keywords 'education', 'teaching', 'learning', or 'curriculum') and sublink Journals
→ Diverse periodical information related to transdisciplinarity

[ITdNet International Transdisciplinarity Net website] Network of Transdisciplinarity Laboratories (TdLabs) on teaching and practicing transdisciplinary research
→ Special Issue International Journal of Sustainability in Higher Education. Volume 7, Number 3, 2006. Applying transdisciplinary case studies as a means of organizing sustainability learning

[Integration and Implementation Sciences Network website (hosted by The Australian National University)]
→ Aiming to develop a new specialisation for researchers focusing on integrative skills and provides a list of researchers, organisations, professional associations and journals, as well as sponsoring projects

[University of Basel]
→ Transdisciplinarity specialised master's degree in sustainable development, approached in an interdisciplinary manner and having a transdisciplinary project work

[ETH-NSSI Transdisciplinarity Laboratory (TdLab), Federal Institute of Technology in Zurich]
→ ETH-UNS Transdisciplinarity Case Studies programme (td CS, since 1994, Michael Stauffacher, Roland W. Scholz) is compulsory at MSc in Environmental Sciences - Major in Human-Environment Systems. Hybrid course combining learning, research, and application used to learn competencies and skills necessary for research in problems of sustainable development. Scientists and non-scientists cooperate for a certain period of time, aspire to a mutual learning process and conduct transdisciplinary research.

→ CCES Winter School «Science Meets Practice», addresses primarily PhD students and postdocs from environmental and natural sciences, engineering, and social sciences working in the fields of sustainability and sustainable development, with the aim to scientists lead a true dialogue with people and institutions outside the scientific community.

[Department of Mechanical Engineering, Texas Tech University, USA]
→ Transdisciplinary Design − Process & Systems Track (Ph.D. Program), expose students to a wide range of topics and will emphasize collaborative, cross−discipline team−based research efforts. Research topics will include design, process and systems.

[University of Western Ontario, Canada]
→ Ecosystem Health Program undergraduate programme for medical students to understand the context of social and environmental risks.

[Faculté Aménagement, d'Architecture, d'Art et de Design, Université Laval, Quebec Canada]
→ Interdisciplinary Research Group on Suburbs (GIRBa, Carole Després) deals meetings, borough colloquiums, objective-defining workshop, participatory design mini-sessions helped to define general orientations and objectives.

[Centers for Behavioral and Preventive Medicine, Brown University (USA)]
→ Transdisciplinary post-doctoral, new faculty, and internship training programmes, aimed at preparing physicians, psychologists, public health, and behavioural/social scientists to work jointly on complex questions.

[The Wageningen Initiative for Strategic Innovation, Wageningen UR (University & Research centre)]
→ variety of learning formats (workshops, courses, creative sessions and scenario-casting techniques with stakeholders) provide professionals with facilities, skills, and moral support.

[Holistic Education Network of Tasmania, Australia]
→ Provide materials and links to organisations with interests in transdisciplinary inquiry, holistic learning, and transformative learning

[Institute for Sustainability and Technology Policy, Murdoch University, Australia]
→ There are 6 key areas, transdisciplinary in that taken together, as an undergraduate degree. Most of the postgraduate degrees and research topics cross over two or more of these key areas. The main aim of ISTP is to enable teaching and learning within the four pillars of education in the context of transdisciplinarity for sustainability (Marinova & Mcgrath, 2004)

[Technical University of Vienna]
→ FACILE is a FACILitated distance learning environment for continuing engineering education, that enhances the knowledge and skills of professionals in their daily work.

[University of Hagen in Germany; British Open University]
→ Internet-based distance courses and cooperates with national and international partner institutions

[NDIT/FPIT, Nachdiplomausbildungé in Informatik und Telekommunikation/Formation Postgrade en Informatique et Télécommunications]
→ Virtual university that provides postgraduate studies and functions as a training and research partnership between universities and private companies in a consortium of over forty institutions.

5.7.4 Approaches to transdisciplinarity in higher education

Generally speaking, academic programmes tend to be located within discipline-dominated institutions rather than autonomous institutions. Beyond the university, transdisciplinary education also occurs in situ, in the workplace and in projects with community stakeholders. It has been introduced as compulsory courses in undergraduate programs and master and doctoral programs, minors, winter or summer courses, workshops related or not to formal programmes, training courses or activities for professionals and other academic modalities. A few universities have implemented experiential learning environments. Some contributions become interesting.

A central role that project work and mutual learning play in transdisciplinary education is viewed in master and doctoral programmes. At the graduate level, Gary Frey (2003) advises, transdisciplinary education is often hindered by limited availability of supervisors in pertinent methods and by problems associated with students' lack of strong disciplinary identity. Frey urges more teamwork, a wider range of courses and seminars, and opportunities to mix with students of different knowledge cultures.

A PhD programme was developed in the framework of the research process 'Designing the Urban: Discovering a Transdisciplinary Method' in the Swiss Midlands (1993-2003), by means of teaching Urban Design with students in mixed groupings (morphological and physiological competences) and producing participatory workshops with population work. From the last evaluation it was recommended framing Ph.D. topics in a way that permits time-limited projects of several years. The average time of the thesis period in the urban design project they described was extended by about 20%, but doctoral students considered the experience to be a valuable supplementary step in their education (Baccini and Oswald in Hadorn et al., 2010). They call attention to the role of workshops and related focus groups set the aim of the programme, updated results, addressed barriers, readjusted priorities and interventions, and dealt with policy issues.

In a master in Wageningen conducted jointly by universities in Ireland and the Netherlands, students are placed in state agencies and private consultancies, and they do field and project work in multiple countries, in addition to learning about pertinent disciplines. At the University of Basel' in the specialised master's degree in sustainable development, after deepening the disciplinary and complementary knowledge and practical training outside the university, an interdisciplinary project has to be carried out and the master's thesis knowledge has to be achieved by transdisciplinary project work. Considerable importance is additionally placed on in analytical and integrative skills, communication, team development and project management in order to facilitate constructive work in transdisciplinary settings (Burger et al., 2000).

At UPC-BarcelonaTech the Master in Sustainability, helded by the Institut of Sustainability IS.UPC, aims to provide advanced training in the field of sustainable human development, to understand the complex interactions between society, technology, economy and natural environment. Students can design and evaluate sustainable global solutions, working in different contexts, interdisciplinary cultural and professional. The course Interdisciplinary workshop, allows students to work together in an interdisciplinary and cooperative dimensions.

In Switzerland in the framework of Graduate Studies and Continuing Education in Transdisciplinarity, the ETH-UNS Case Studies courses, form a compulsory part of environmental science education at the Federal Institute of Technology in Zurich. The programme has conducted one case study per year since 1994. Walter, Wiek and Scholz (Walter et al. in Hadorn et al., 2010) describe how teaching, research, and application, are combined within a single project. Mutual learning is intrinsic to Transdisciplinarity Integrated Planning and Synthesis (TIPS). Students develop knowledge and methods of science and collaborative skills by working in study teams and with case agents on complex problems in areas such as sustainability, agriculture, reintegration of industrial sites, urban and regional development and the eco-efficiency of environmental interventions. The process is supported by a variety of case study methods, including formative scenario analysis, modelling systems dynamics, integrated risk model, future workshops, and life-cycle assessment.

Courses in Transdisciplinary Programs in Design, Process and Systems are taught via on-site visits and distance learning by the Institute for Transdisciplinary Education and

Research, Department of Mechanical Engineering at Texas Tech University (USA) that has implemented in this manner a new vision of engineering.

The minor Sustainability in Humanities, Leuphana, offered at Lüneburg confronts future oriented problems, analyses the consequences of global change, and presents sustainable solutions. The minor contains the course Interdisciplinary and Transdisciplinary Collaboration, that aports knowledge generation and integration, communication within the framework of interdisciplinary and transdisciplinary collaboration.

At the Institute of Behavioural Science, Semmelweis University of Medicine, Budapest, Hungary, different subdepartments teach the different branches of behavioural science separately but all applying the biopsychosocial paradigm in an interdisciplinary, integrative way. This model is present at different levels of teaching: the undergraduate level (for medical and health science students), the postgraduate level (postgraduate training for specialists, and teachers) and the doctoral level (for both medical and non-medical graduates) (Piko and Kopp in Hadorn et al., 2010).

At the University of Western Ontario in Canada, the Ecosystem Health Program has brought specialists together with the lay community in an undergraduate programme aimed at helping medical students understand the context of their patients' lives and social and environmental risks (McMurtry, 2000).

In Catalonia, The research group Education Research Transdisciplinary Group (GRET), Facultat de Ciències de l'Educació, Universitat Autònoma de Barcelona implements a first-year course of Faculty of Education: Society, Science and Culture, by a trandisciplinary methodology. A large teaching team designed a wide variety of methods of transdisciplinary implementation based on the labyrinth theory, and focusing on what they call "design constellations"[23].

Professionals need training in the workplace as well. The most complex challenge, Nicolescu stresses, is the teaching of teachers and developing appropriate pedagogy. The Wageningen Initiative for Strategic Innovation Jelleke De Nooy-van Tol (2003) reports[24], has provided professionals with the extra time, facilities, skills, and moral support to cope with complexity and value systems in their daily surroundings. Project leaders learn in the context of an actual project, following criteria that define the characteristics and preconditions for transdisciplinary research. A variety of learning formats has been used, including a formal course in communication skills and a pilot course in systems approaches, an atelier in the form of creative sessions with all stakeholders, support for using scenario-casting techniques and system approaches, and workshops for scientists involved in organic agriculture.

A project of the Technical University of Vienna, FACILE enhances the knowledge and skills of professionals in their daily work. FACILE is the acronym for FACILitated distance learning environment for continuing engineering education. Cyberspace is a rapidly expanding forum for academic coursework, professional training, and resources for transdisciplinary education.

Research and action activities, in turn, triggered community education initiatives. In a case study of retrofitting post-war suburbs in Quebec (Canada) depicts an intensive

[23] It started with a first experience based on the narrative (P. Ricoeur, 2000) and using macroconcepts and constellations. Then are applied a fruitful field of methods that have been extended to the use of visual metaphors in the sense of the life experience of G. Lakoff and M. Johnson, and of the fusion of horizons formulated by Gadamer http://ciret-transdisciplinarity.org

[24] http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/centre-for-development-innovation.htm

participatory design process led by the Interdisciplinary Research Group on Suburbs (GIRBa) at Université Laval (Després et al. in Hadorn et al., 2010). In all phases of the implementation (phase of decision makers and planners; general orientations and objectives; implementation strategy) there were one-day mini-colloquia, objective defining and criteria design workshops, and participatory design sessions where participants discussed, interpreted and defined maps of the city and suburban boroughs. The GIRBa also plays an incubator role for graduate students in architecture and urban planning projects.

In the search of adequate pedagogies, Gidley (2012) bets for the need for the transition from formal, factory-model schooling and university education to a plurality of postformal or evolutionary pedagogies. For herself evolutionary pedagogies 'is one that connects education more consciously with the evolution of new patterns of thinking that appeared in so many disciplines and fields throughout the 20th and into the 21st century' and emphasises 'it does not make any sense to educate in the 21st century for 19th century mindsets'. She makes a huge relation of publications about emerging pedagogies that are reflecting one or more of the features of postformal, integral or planetary consciousness. an authentically futures-oriented education would embrace the rich diversity of postformal, integral and planetary pedagogical approaches that are out there, globally, in view of the critical planetary times.

Dealing with the complex problem of sustainable development requires, besides analytical capabilities and deterministic process planning, creativity, social competencies and specific communication skills. The process of educating for sustainable development and practical applied sustainability, becomes sustainable when students experience the process of sustainable development instead of purely memorizing its characteristics (Marinova & Mcgrath, 2004). Teachers and researchers have to abandon the role paradigm of the teacher as provider of information and the students as "consumers" of the provided information. Dinamic mutual learning process based on real-world cases requires an interdisciplinary point of view, transdisciplinary problem-solving processes, and self-regulated and self-responsible learning, where student decide which tools to apply in the process.

Careful attention is needed for instructors to design, run and implement courses in sustainability topics that enable students from widely different backgrounds and levels of self-directedness to engage with, take responsibility for, and transform their behaviours in favour of sustainability (Steiner & Posch, 2006)

5.7.5 How to assess transdisciplinarity learning process

Assessment of learning about transdisciplinarity for sustainability presents a novel challenge that is integral to the challenge of assessing progress toward sustainability as a whole (Holden et al., 2008). There is neither standarized assessment practices on transdisciplinarity education processes, nor many studies developing the topic.

In their work, Brundiers & Wiek, (2010) applied an evaluative scheme to two sustainability research-education projects in Switzerland to test its applicability and to identify achievements of the projects and the areas where improvement is needed. They doesn't conduct a rigorous evaluation, so they analyzed process documents and observations of interactions (minutes of meetings, personal notes); student material (conceptual papers, presentations); and results of the exit surveys, which are completed by all project participants and are designed to evaluate the quality of the process and outcomes. Areas for improvement include collaboration between academics and practitioners, joint problem definition, and the guidance of students to participate successfully in collaborative, real-world projects. They introduced the Transacademic Interface Manager (TIM) as a neutral person who facilitates the transacademic collaboration. The TIM takes on the roles of facilitator (mediation, translation), coach for students (interpersonal skills, project management skills), and project manager (coordination, administration, resources, schedules). Thanks to this role, they had access to the informal, and usually inaccessible, observational data that the TIM records in internal memos of meetings and interactions.

In another Project, Angles on Green Building-AGB, as part of the evaluation, post-course interviews with six students, were conducted by a research assistant. These students were asked to provide feedback on their learning, their assessment and critiques of the course, and broader comments on the role of higher education in sustainability and green building, in a semi-structured format. A post-course focus group was also held with both the instructor team and a sample of the practitioners who had visited the course. The results of these interviews and focus groups were analyzed for the insight they provide into the most significant learning experienced by students, instructors and visiting practitioners, and the areas of greatest disappointment or frustration. Often, instructors expect to influence students' knowledge and understanding based solely on the content of their courses. In contrast, the analysis in this article examines the impact of the course's unique process on students' sustainability learning.

A major conclusion from this assessment of the learning in AGB was that they would all be more effective in their work toward sustainability if they had the opportunity to think more about how they learn. Engaging in greater reflection involves taking on not just additional work but also additional responsibility. They find that an unanticipated analogy emerged between the kind of additional responsibility central to the course and the additional responsibility that is central to moving toward sustainability. They found that the area most drastically in need of improvement is the mismatch between course structure and pedagogy, and the diverse learning stages of students. They feel keenly the need for additional research to connect research on how people learn with research on pedagogy, or how to teach people how to learn (Holden et al., 2008).

5.8 Institutional framework: from HES to UPC-Sostenible 2015

5.8.1 Higher Education for Sustainability (HES)

While complex and uncertain sustainability problems are posed, the constant technical and scientific developments and their practical applications to solve problems in ecosystems, often become a new source of long-term risk (Horlick-Jones & Sime, 2004). In response to this situation, post-normal science (Funtowicz & Ravetz, 1993) assumes that, science must takes into account the unpredictability, an incomplete control and the recognition of the importance of a plurality of legitimate perspectives.

In these latest decades of the 20th century, universities began to mobilize. Universities stated they had the responsibility to teach the moral vision and technical expertise necessary to ensure the quality of life for future generations, sustainable development being the context in which higher education should focus its mission (Blaze et al. 2002). In this regard, the role of higher education is stressed to guide a new perspective on learning. An initial coordination between international organisations that subscribed some declarations, resulted on the formation of the Global Higher Education for Sustainability Partnership (GHESP, 2000), representing over 1000 universities with the commitment to adopt sustainability. In 2001 they signed the Lüneburg Declaration committing themselves to action:

- Promoting subscription and implementation of previous declarations (Kyoto, Talloires, Copernicus)
- Creating a tool of performance addressed to universities, business agents, administrators, teachers and students, designed to go from commitment to action.
- Improving the development and networking of regional centres of excellence in developed and developing countries.

In December 2002, the United Nations General Assembly adopted by consensus the resolution 57/254 on the United Nations Decade of Education for Sustainable Development[25], from 2005 to 2015, recommended by the World Summit on Sustainable Development. In this context education for sustainable development (ESD), became central in many publications, universities units, networks, conferences and events (Engineering Education in Sustainable Development (EESD), European Networks Conference on Sustainability in Practice (ENCOS), International Symposium IGIP/IEEE/ASEE Local Identity, Global Awareness, Engineering Education Today, Environmental Management for Sustainable Universities (EMSU), Congreso Iberoamericano de Educación Ambiental, etc.).

5.8.2 EHEA framework

The European Higher Education Area (EHEA)[26] also known as “The Bologna Process” has adopted a system of easily readable and comparable degrees, which requires outcomes-focussed qualification frameworks that share common and clear methodological descriptors. This structure facilitate the exchange of students, trainers, knowledge, between the comparable and connectable three cycle degree system:

- First cycle (Bachelor level, 180-240 ECTS[27])
- Second cycle (Master level, 90-120 ECTS beyond the 1st cycle; minimum of 60 credits at the level of the 2nd cycle)
- Third cycle (PhD level)

Qualifications are expressed on the basis of explicit reference points using learning outcomes and competences, levels and level indicators, subject benchmarks and qualification descriptors (Bologna Working Group on Qualifications Frameworks, 2005). The European Education Ministers (September 2003) encourage the member States to elaborate an overarching framework of comparable and compatible qualifications for the EHEA (JQI, 2004), trying to describe qualifications in terms of workload, level, learning outcomes, competences and profile. ‘Dublin descriptors’[28] describe the competences that students may acquire in the first, second and third level of higher education cycles and are a reference in Europe when defining the new EHEA Bachelor and Masters degrees.

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[25] The United Nations Decade of Education for Sustainable Development, began in 1 January 2005.
[26] In catalán: Espai Europeu d’Educació Superior, EEES
[27] ECTS (European Credit Transfer System) is the unit for the students’ work load (1 ECTS = 25÷30 hours of student work) and 60 ECTS normally corresponds to one year of fulltime studies =1500 hours of student work.
[28] Adopted by European Ministers of Education in May 2005. See: Framework of qualifications for the European Higher Education Area <http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/QF-EHEA-May2005.pdf>.

5.8.3 Competences in engineering education

The 2nd International Conference on EESD [29] scientific committee provided the Barcelona Declaration that brings orientations to be taken to progressively implement Education in Sustainable Development (ESD) objectives into concrete actions in engineering field. It's stated that "*a new kind of engineer is needed, an engineer who is fully aware of what is going on in society and who has the skills to deal with societal aspects of technologies*" (De Graaff et al., 2001). Quoting Barcelona Declaration (2004):

> *(…) Engineers must be able to:*
>
> *- Understand how their work interacts with society and the environment, locally and globally, in order to identify potential challenges, risks and impacts.*
> *- Understand the contribution of their work in different cultural, social and political contexts and take those differences into account.*
> *- Work in multidisciplinary teams, in order to adapt current technology to the demands imposed by sustainable lifestyles, resource efficiency, pollution prevention and waste management.*
> *- Apply a holistic and systemic approach to solving problems and the ability to move beyond the tradition of breaking reality down into disconnected parts.*
> *- Participate actively in the discussion and definition of economic, social and technological policies, to help redirect society towards more sustainable development.*
> *- Apply professional knowledge according to deontological principles and universal values and ethics.*
> *- Listen closely to the demands of citizens and other stakeholders and let them have a say in the development of new technologies and infrastructures.*
>
> *(…) Universities now have the opportunity to re-orient the traditional functions of teaching and research, by generating alternative ideas and new knowledge. They must also be committed to responding creatively and imaginatively to social problems and in this way educate towards sustainable development.*

There have been many approaches to define the SD learning outcomes and/or competences that engineering students should have when graduating, as the UK Standard for Professional Engineering Competence (UK Engineering Council, 2005); the Accreditation Board for Engineering and Technology (ABET, 2007); the Criteria for Academic Bachelor's and Master's Curricula of Delft University of Technology, Eindhoven University of Technology and the University of Twente, The Netherlands; the CDIO Syllabus of CDIO™ INITIATIVE [30] (at an international level). The commonalities of these SD competences frameworks are related to critical thinking, systemic thinking, inter-trans-disciplinarity and values and ethics (Segalàs, 2009, 2012).

5.8.4 UPC-Sostenible 2015

"The Technical University of Catalonia, as a institution generating and transmitting knowledge, must promote environmental protection and sustainable development, both in training and research and institutional activities." UPC Statutes (2003). Article 4 (Guiding principles)

The Technical University of Catalonia- Barcelona Tech (UPC) incorporated an institutional commitment to approach sustainability in all areas of work. Aimed to this

[29] See: http://www.upc.edu/eesd-observatory/what
[30] CDIO stands for Conceive- Design- Implement- Operate. See: <www.cdio.org>. CDIO formed focus groups of industry representatives, engineering faculty and other academics, university review committees, and alumni in order to compile a list of the abilities needed by engineers.

goal, there were two consecutive environmental plannifications (1996-2001 and 2001-2006) and many internal and external activities. In 2006 the Governing Council approved the first "UPC Sostenible 2015"[31] Plan (UPC, 2006), as an institutional strategy, engaged as a result of a participatory process which brought together the university community-students, staff and administration services and faculty, as well as external stakeholders.

The strategy was based on four areas (water, energy, facing three sectors related to research, training and internal management, and tied to a more global interaction and social commitment. In this latter area the UPC marks its roadmap through participation and commitment to the challenges of sustainability of their local, regional and international environment (UPC, 2006). In the process to strengthen this strategy, various internal and external conferences and forums (EESD 2004, EMSU 2008, Congress UPC Sustainable 2007 and 2009, Forums UPC Sustainable 2005 and 2007) have drawn their conclusions, paragraphs and agreements in line with the commitments made in the Plan UPC Sustainable 2015.

As a result of these activities, at the beginning of 2008 the Declaration of Sustainability at UPC[32] was adopted, that is the main reference in terms of the UPC institutional commitment for sustainability. The text was drafted by a working group and discussed at the 1st Congress UPC Sustainable 2015. This statement refers explicitly to different criteria that should be included when considering the academic university: "*to develop academic activity without promoting inequality and mainly orienting it to social needs*". In line with this commitment, in April 2008 the Governing Council approved generic competition "Sustainability and Social Commitment", as one of the seven to reach the students in all degree programs.

In this institutional context, at the end of 2009, the Institute of Sustainability[33] at UPC was created with the mission of creating the technical and conceptual tools necessary to help transform the production model towards sustainability. The institute became an ideal framework to implement the ideological and conceptual framework developed in the area of social interaction and engagement, conceived as the essence that must permeate the university activity[34]. For this reason, during the review of the UPC Sustainable 2015 Plan (wich took place in the 2010-2011 academic year) the proposal to institutionalize a strategy that permeates social involvedment and interaction criteria for the whole acadèmic and management activity o fthe UPC arose. In this proposal, the Institute for Sustainability should be entitled to energize a process that strengthens and promotes actions, projects and educational lines and research that promote interaction and social commitment in the field of sustainability at UPC.

The aproved 2nd phase (2011-2015) of the UPC Sustainable 2015 Plan [35] contemplates two estrategic dimensions: 4 *transverse lines* and 6 *tematic lines*, with associated objectives and actions. The thematic lines define the sustainability challenges that UPC can contribute, as a technological university. The transverse lines define the transdisciplinary way in which the university must interact with its complex environment (governance, values, acting manner). The renovated Plan defines:

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[31] See: http://www.upc.edu/mediambient/Pla%20UPC%20Sostenible%202015.pdf
[32] See: http://www.upc.edu/sostenible2015/ambits/el-compromis-i-la-interaccio-social/1-declaracio-de-sostenibilitat-de-la-upc
[33] See: http://is.upc.edu/l-institut/presentacio
[34] See *Informe ICS* at: http://www.upc.edu/sostenible2015/pla-upc-sostenible-2015/Seminaris/documents
[35] See: http://www.upc.edu/sostenible2015/pla-upc-sostenible-2015/pla-upc-sostenible-2015-2a-fase-2011-2015/documents-aprovats-consell-de-govern/PLA%20UPC%20SOSTENIBLE%202015F2%20v3_CG.pdf/view

Transverse line 2 - Interaction and social engagement: the demands of the environment
Objective 2.A: Generation of tools to respond to social demands and support the preservation of the land and the actions of social networks that promote sustainability. Interact with the environment in a purposeful and active.
Objective 2.B: Strengthen educational programs in sustainability with tools and mechanisms that promote active learning, based on the analysis of current social problems.
Objective 2.C: Provide technical and scientific criteria and arguments for government, business and society in general, for making decisions, taking a pro-active attitude.
Objective 2.D: Develop demonstration projects (when convenient collaborating with other universities and institutions) in scenarios restriction of resources (including their own UPC) and consider the environmental and social impacts of technology.
Objective 2.E: Encourage participation in competitive research projects in the field of sustainability.
Transverse line 3 - Interaction and social engagement: campus as laboratories
Objectiu 3.A: Develop plans for sustainable management of the UPC campus that consider the needs of the campus and its resource management and infrastructure sustainability criteria
Objective 3.B: To strengthen research and teaching on sustainability at the UPC campus priority lines of action plan issues related to academic specialties and promoting the use of campus spaces for experimentation.

In the establishment of the main functions and activities[36] associated to the UPC 2nd Phase Sustainable Plan 2015, the IS. UPC has the following ones:

Generic roles
- Promotion and coordination of UPC Sustainable Plan 2015
- Promoting the Sustainability Committee of the UPC
- External coordination: Participation in working groups (i.e. CADEP-CRUE[37]) and other networks
- Counseling, further studies and/or quality control of UPC processes

Specific roles
- Promotion of inter- and trans-disciplinary research, development and innovation of - Sustainability and Environmental Sciences (ES) (scientific production, projects and agreements)
- Promotion of Science and Technology for Sustainability applied to UPC (UPCLab)
- Graduate and permanent programs in Sustainability (own) and ES (shared)
- Promoting participation in education and applied research competition Sustainability and Social conjunction with Education Sciencies Institute of UPC (ICE)

This thesis proposal reflects the concern expressed by the university community during the Plan review. It addresses the relationship between the university and society from the science of sustainability, setting strategies in the academic and management activities of the university, through transdisciplinary practice. It forms part of the institutional and thematic framework of the university, focusing and trying to answer several questions, needs, ideas and actions established as institutional commitment.

[36] See: http://www.upc.edu/sostenible2015/pla-upc-sostenible-2015/pla-upc-sostenible-2015-2a-fase-2011-2015/documents-aprovats-consell-de-govern/plaUPCsoste2015F2_Funcions_Accions_vCG.pdf/view
[37] The Conference of Rectors of Spanish Universities (CRUE, 1994), brings together 75 Spanish universities, with the aim of contributing to the promotion and improvement of higher education, through inter-university cooperation and dialogue with the social partners, for the development, improvement and progress of society. The CADEP, is the CRUE sectoral commission for Environmental Quality, Sustainable Development and Risk Prevention in universities. The working group was created (2002) to collect the experience of universities on environmental management, greening and advances in risk prevention work and continued cooperation.

6 Pla de treball

6.1 Revisió bibliogràfica

Es continuarà la revisió bibliogràfica tenint en compte les fonts d'informació identificades com a rellevants en l'àmbit de la transdisciplinarietat, la sostenibilitat i l'educació superior. En aquest sentit, sabem ja que la Sostenibilitat forma part dels debats sobre l'educació superior i es realitzen regularment múltiples **congressos internacionals.** Igualment la transdisciplinarietat apareix com a tema transversal i cada cop més, central en un nombre creixent de congressos i jornades. Algunes xarxes internacionals apleguen institucions, iniciative i individus que actúen entorn la transdisciplinarity. En aquest sentit destaquem:

- ITdNet - International Transdisciplinarity Net on Case Studies for Sustainable Development[38]. http://www.uns.ethz.ch/translab/itdnet
- I2S - Integration and Implementation Sciences of Australian National University (ANU). http://i2s.anu.edu.au/
- td-net - Network for Transdisciplinary Research of Switzerland. www.transdisciplinarity.ch
- INIT - International Network for Interdisciplinarity & Transdisciplinarity [39]. http://www.inidtd.org

Es continuarà revisant i aprofundint en l'aportació que fan algunes revistes internacionals i nacional. Pel fet que les publicacions en transdisciplinarietat són relativament recents i poc organitzades. Sovint cal buscar de baix a dalt, partint de la metodología o el tipus d'enfocament del tema que es tracta en un article. En aquest sentit es revisarà la revista ***Journal of Cleaner Production***, especialmet alguns dels seus volums, com *Learning for sustainable development in regional networks* (Volume 49, June 2013), *Environmental Management for Sustainable Universities (EMSU) 2010, European Roundtable of Sustainable Consumption and Production (ERSCP) 2010* (Volume 48, June 2013). No obstant he percebut una tendencia a tractar el tema de forma central o transversal en algunes revistes. La revista ***Sustainability Science***, ha publicat recentment l'especial *Sustainability science: bridging the gap between science and society* (Volume 7, Issue 1, Febrer 2012). També la revista ***International Journal of Sustainability in Higher Education***, compta amb l'especial *Applying transdisciplinary case studies as a means of organizing sustainability learning* (Volume 7, Number 3, 2006). La revista es publicada conjuntament amb l'*Association of University Leaders for a Sustainable Future* (ULSF)[40], de la qual resulta interessant

[38] *Core (active) members of the ITdNet*: ETH Zürich - NSSI Social and Natural Science Interface, Switzerland (Pius Krütli, Michael Stauffacher); Ludwig-Maximilians-University Munich - Chair for Human-Environment Relations at the Department of Geography (Claudia Binder); Chalmers & Gothenburg University - GMV Centre for Environment and sustainability, Sweden (Per Knutsson, Lena Viktorsson); Karl-Franzens-Universität Graz - ISIS Institute for Systems sciences, Innovation and Sustainability, Austria (Alfred Posch, Gerald Steiner, Clemens Mader); Leuphana University Lüneburg, Germany (Daniel Lang, Ulli Vilsmaier, Simon Burandt); University of Surrey, Centre for Environmental Strategy, UK (Stephen Morse, Simon Bell). *Associate members of the ITdNet*: BOKU - University of Natural Resources and Applied Life Sciences, Vienna, Austria (Andreas Muhar, Bernhard Freyer, Sebastian Helgenberger); International Centre for Integrated assessment and Sustainable development (ICIS), Maastricht University, Netherlands (Pim Martens); Stellenbosch University - Transdisciplinary Sustainability Analysis Modelling and Assessment HUB, South Africa (John Van Breda); Arizona State University - School of Sustainability, US (Arnim Wiek); Humboldt-Universität zu Berlin - Geographisches Institut, Germany (Alard H. Mieg); Climate Change Program CATIE, Costa Rica (Raffaele Vignola)

[39] Network attended by representatives from the US-based Association for Integrative Studies (AIS), the European-based Transdisciplinarity-Net (td-net), and the Center for the Study of Interdisciplinarity (CSID) at the University of North Texas in the US.

[40] http://www.ulsf.org

també la informació publicada, així com la d'associacions com la *Association for Interdisciplinary Studies* (AIS) o col·legis professionals de l'àmbit de l'enginyeria com l'*American Society for Engineering Association.* Altres revistes on apareix el tòpic són *Futures*, *International Journal of Sustainability in Higher Education*, *Ecological Economics*, *Innovative Higher Education*, *Journal of Environmental Management*, *American Journal of Preventive Medicine*, etc.

D'alta banda, es consultarà obres de referència sobre sostenibilitat, transdisciplinarietat i interdisciplinarietat. Pel que fa a la transdisciplinarietat, són interessants i una bona font de recursos, les publicacions resultants de congressos y conferències internacionals.

En Relació a l'**Espai Europeu d'Educació Superior**, la informació es troba en les pàgines web de cadascuna de les cimeres que es van realitzant. La UPC va informant a la pàgina web on s'actualitza la informació relativa a l'EEES[41]. En aquest sentit també cal considerar la *6a Conferència Internacional de Barcelona sobre Educació Superior*, organitzada per la Global University Network for Innovation (GUNi) amb el títol *'Let's build Transformative Knowledge to Drive Social Change'* s'ha celebrat del 13 al 15 de maig de 2013, que ha centrat el debat en la relació entre el coneixement i el canvi social.

Respecte a **metodologies i estratègies pedagògiques**, l'ICE de la UPC és una bona Font d'informació. En aquest institut s'ha format un grup de professors en aprenentatge cooperatiu que realitza trobades annuals, per a analitzar les experiències dels seus membres. Per altra banda es preveu de plantejar col·laboracions amb el **grup de recerca** Society, Science and Culture, Education Research Transdisciplinary Group (GRET) de la Facultat d'Education, Universitat Autònoma de Barcelona. Igualment es continuarà la tasca de participació i seguiment al **grup de treball CADEP**, la comissió sectorial de la CRUE per la Qualitat ambiental, el Desenvolupament sostenible y la Prevenció de riscos en las universitats.

6.2 Definició metodológica

La metodologia a seguir per a assolir els objectius fixats en aquest treball segueix un camí que s'inspira en la segona part del treball d'investigació de Konstantin Stanislavski[42], en el teatre. El personatge parteix d'unes circumstàncies donades, en un escenari determinat. L'objectiu és el resultat, on vol dirigir-se i s'explica amb una frase concreta que ha de convidar a l'acció. Els conflictes i les accions (propies i reactives) l'obligaràn a crear estrategies per a assolir l'objectiu. Com més creativas son las estrategias mas interesante es la escena i qualsevol procés. El punt de partida i l'objectiu són clars, el *com*, va arribant amb l'acció.

6.2.1 L'escenari, d'on partim. Per què la transdisciplinarietat en la formació superior en enginyeria per a la sostenibilitat

L'anàlisi de la necessitat d'introduir la Transdisciplinarietat en la formació d'enginyeria per a la Sostenibilitat, es desenvoluparà en dos àmbits:

41 http://www.upc.es/eees

42 En el mètode de les accions físiques "la petita veritat de les accions físiques posa en moviment la gran veritat dels pensaments, les emocions i les experiències". És a dir s'aprèn a partir del fer. La voluntat de l'actot posa la seva atenció en l'acció y d'aquí sorgeix l'emoció. El seu treball anterior, el 'realisme psicològic', postula que l'actor no ha de representar, sinó viure. És a dir sentir, pensar i comportar-se sincerament en les circumstàncies de la ficció. Va recórrer a disciplines alienes al teatre (fisiologia, història, psicología) per entendre la conducta humana.

- de quina manera la transdisciplinarietat està íntimament lligada al plantejament y desenvolupament dels reptes de la sostenibilitat
- de quina manera la transdisciplinarietat representa una millora en l'aproximació de la formació i activitat profesional dels enginyers
- de quina manera la transdisciplinarietat esdevé una evolució a la situació institucional present

Als primers capítols d'aquest treball, es fa una aproximació a la relació entre sostenibilitat i transdisciplinarietat. Als capítols 1.5 i 1.6 es relacionen experiències i demostracions d'introducció de la transdisciplinarietat a diferents contextes educatius, aportant elements per a concebre la millora que representen. L'últim capítol contextualitza l'interès d'aquesta tesi en el marc institucional de la UPC.

6.2.2 L'objectiu, on volem arribar. Què cal assolir per a una formació superior transdisciplinar en enginyeria per a la sostenibilitat

A partir d'analitzar les necessitats de l'entorn i la capacitat de resposta de l'enginyer i l'enginyera envers aquest, cal definir acuradament l'estructura bàsica, la tendencia i l'evolució que ha de contemplar una formació amb base transdisciplinar, per a poder millorar la sostenibilitat del sistema educatiu. Quins són les aptituds, metodologies, conceptes i coneixements relacionats amb el la transdisciplinarietat ha s'han de tenir en compte en la formació amb base transdisciplinar.

En l'anàlisi de les circumstànceis de partida, es plantegen problemes i mancances a resoldre, els quals indiquen quines són les eines requerides pels enginyers i enginyeres tant en l'àmbit dels coneixements, com de les aptituds, valors i eines metodològiques amb la finalitat que aquests enginyers i enginyeres siguin capaços de resoldre els problemes i mancances advertits i de no crear-ne de nous.

La tasca consistirà, en primer terme, a aprofitant l'expertesa en formació transdisciplinar en enginyeria envers el desenvolupament sostenible de diversos grups de treball i universitats d'arreu del món (caldrà identificar els interlocutors idonis), a mantenir reunions amb els responsables d'aquesta formació per recollir les seves experiències i consells. En l'apartat 5.7, a títol d'exemple del que serà la tasca de prospecció, s'examina la formació que realitzen diverses institucions de formació tecnològica superior en sostenibilitat, en transdisciplinarietat. A partir de l'anàlisi de la informació recollida, es farà una proposta de la formació que cal que els enginyers i enginyeres rebin.

6.2.3 L'estratègia, el camí. Com introduïr de eficientment la transdisciplinarietat a la UPC

L'estudi de les diferents metodologies i les experiències realitzades a les universitats capdavanteres en l'ensenyament de la sostenibilitat en l'enginyeria, aportarà elements sobre com introduir i/o aplicar de manera eficient la transdisciplinarietat a la UPC, quin tipus d'estructura, metodologia, eines, són les més adequades. Sorgeixen algunes preguntes que caldrà afrontar:

- Quina formació del professorat cal per a la introducció de la transdisciplinarietat en els estudis tecnològics. En aquest punt és necessari l'anàlisi de la idoneïtat de les tècniques pedagògiques i estructures metodològiques del professorat.

- Quina relació entre disciplines i amb els actors socials es necessaria per a orientar la formació cap a la transdisciplinarietat

- Com s'entén la transdisciplinarietat per la diferents disciplines de la jerarquía de la transdisciplinarietat. Es realitzarà una prospecció sobre com s'entén, que és la transdisciplinarietat, per a docents de les diferents disciplines de la jerarquía de la transdisciplinarietat (Max-Neef, 2005), per tal de obtenir una aproximació de com s'entén un procés de formació transdiciplinar a l'entorn universitari.

- Què cal a nivell de organització curricular per a que sigui viable la introducció de la transdisciplinarietat en sostenibilitat
- Quins programes de recerca en sostenibilitat, permeten l'adquisició de la transdisciplinarietat
- Identificar bones practiques d'aprenentatge transdisciplinar i proposar adaptacions a la UPC
- Identificar bones practiques en les àrees de gestió sostenible de la universitat i proposar-ne de noves

L'EEES representa el marc per a les recomanacions per als plans d'estudis, ja que aquest marcarà la seva estructura curricular i temporal i les competències previstes a assolir. En l'apartat 1.6 es dóna una aproximació a l'evolució de l'àmbit europeu.

6.2.1 Integració. Tasques a realitzar

En la següent figura es mostra la relació entre les variables que determinaran el resultat de l'estudi aquí iniciat. L'objectiu que es vol assolir forma part i inclou el procés de treball i l'escenari inicial d'on es parteix.

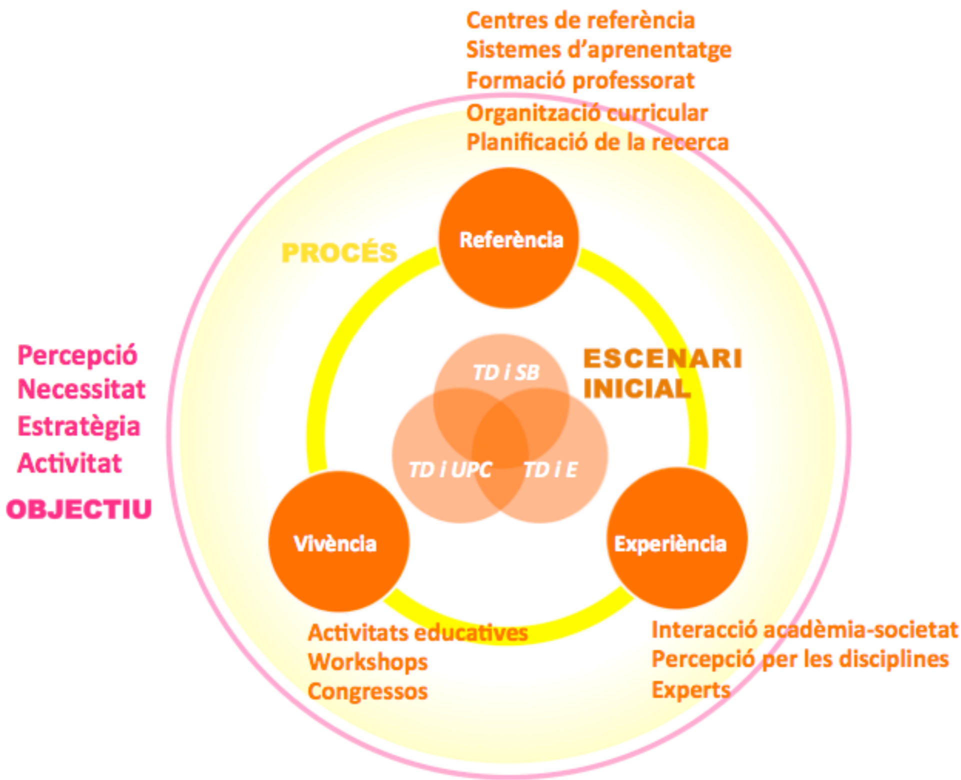

Figura 5. Esquema de la interrelació entre les parts del procés i les tasques a realitzar.

Totes les parts del procés están interrelacionades, afecten i modifiquen les altres. El fluxe d'informació és circular, de manera que totes elles poden anar avançant de forma simultània. Els resultats influencien els diferents estadis i evolucionen cap al resultat final, l'objectiu. Un cop establert el procés i els actors necessaris a l'hora de desenvolupar el treball, podem precisar quines són les tasques que cal dur a terme en cadascuna de les etapes del treball, tal com es pot observar en la següent taula (Taula 1).

Tasques / Objectius	D'on partim	On volem arribar: Què	On volem arribar: Com	On volem arribar: Per on
Recerca bibliogràfica	TD en: - educació superior - enginyeria per a la sostenibilitat (SB)	Conceptes, competències, valors, aptituds	Metodologies pedagògiques, estructures	Universitats i congressos a l'EEES i internacionals
Recerca d'universitats i individus amb expertesa	-	Analitzar experiències en TD per a la SB		-
Recerca de congressos i activitats educatives	-	Analitzar experiències en TD per a la SB		
Evidencia de les activitats educatives (cultivate interactional expertise, Wiek et al. 2011)	-	Escollir i fer vivencials les activitats amb experiència contrastada en TD per la SB		-
Definir indicadors i correlacions	-	Què volem valorar i com ho valorem		-
Dissenyar entrevistes i enquestes (questionari i mapa conceptual)	- Disciplines de la "jerarquia de la TD" - Experts en TD	Escollir destinataris i metodologia		-
Dissenyar i realitzar workshops/focus groups	- Disciplines de la "jerarquia de la TD" - Experts en TD	Escollir destinataris i metodologia		-
Entrevistes amb els experts	-	Visitar les universitats i entrevistar-se amb els experts		
Passar enquestes	-	Realitzar i dur a terme l'enquesta		
Anàlisi entrevistes, enquestes i tallers/focus groups	-	Anàlisi de dades		-
Resultat del treball	Segons recerca bibliogràfica	Segons dades recollides, resultats d'experiències i bibliografia		Segons recerca bibliogràfica i resultats dels apartats anteriors
Conclusions	Recomanacions del què, com i on s'ha d'introduir la TD per a la SB en enginyeria			
Redacció	Redacció de la tesi			
Defensa	Defensa de la tesi			

Taula 1. Relació de les tasques a realitzar amb els objectius de la tesi

6.2.4 Treball de camp

El treball de camp consistirà en la realització d'**entrevistes** amb els experts que prèviament s'hauran identificat, i a realitzar **tallers/focus grups**, en diferents contexts acadèmics. Les entrevistes i enquestes (questionari i mapa conceptual) a alguns experts i professors, es realitzaran aprofitant l'assistència a cursos i congressos, així com a activitats relacionades amb altres tipus de projectes europeus en els que participa l'autora[43]. Respecte a les enquestes a alumnes, es preveu realitzar una enquesta als estudiants matriculats a diverses Escoles d'Enginyeria que imparteixin cursos de desenvolupament sostenible, abans i després de realitzar accions formatives determinades amb l'objectiu de valorar la seva eficàcia.

Els centres que es prendran com a referencia, per la seva trajectòria en l'aplicació de la transdisciplinarietat i per la seva relació en diferents sentits amb el grups de treball de l'autora (al IS.UPC, àrea d'Educació; GR7-STH[44]), són els següents:

→ ETH, ETH-NSSI Transdisciplinarity Laboratory (TdLab)
http://www.uns.ethz.ch/translab/

→ Leuphana, Faculty Sustainability,
http://www.leuphana.de/en/faculty-sustainability.html

→ ASU, Global Institute of Sustainability
http://sustainability.asu.edu/

És previst de participar en els següents esdeveniments:

- De forma virtual, al I2S First Global Conference on Research Integration and Implementation (8 al 11 setembre 2013). Els objectius del congés són: A) Vincular les xarxes, reunint investigadors i educadors que utilitzen enfocament basats en sistemes, orientats a l'acció, multidisciplinari, interdisciplinari, o transdisciplinaris. B) Fer balanç: recollir experiencies d'aprenentatge a partir d'estudis de casos; elaborar conceptes i mètodes eficaços. C) Planificar per al futur: identificar un terreny comú; establir sinergies; unir esforços.
- A Leuphana, Lüneburg, al I2S Co-Conference, Lüneburg, (9 al 10 setembre 2013). De forma alternativa a l'anterior. L'any 2014, al Td Summer School 2013, (1 al 10 setembre)
- A Wislikofen, Switzerland, CCES Winter School «Science Meets Practice» (gener-febrer 2014)
- International conference in Engineering Education in Sustainable Development EESD15, Vancouber (primavera 2015)

Es realizarà o participarà tallers i seminaris:

- Al CENEAM, Valsain, Segovia, en el marc del Doctorat en Educació Ambiental, realització d'un taller en transdisciplinarietat (octubre 2013).
- A Bosnia i Herzegovina, a la tardor de 2014, participación al Backasting Workshop en Community Energy, que s'organitzarà en el marc del projecte TEMPUS SDTRAIN (tardor 2014)

[43] L'autora participa, en els projectes TEMPUS CREDO http://www.eucredo.info/, TEMPUS IEMAST http://www.iemast.info/ i TEMPUS SDTRAIN http://www.webforum.com/sdtrain/web/page.aspx?refid=30, així com al Programa Intensiu ERASMUS STD http://is.upc.edu/seminaris-i-jornades/seminaris/std-2013.
[44] L'autora forma part del Grup de Recerca Sostenibilitat, Educació i Tecnologia (GR7) de la Research Unit in Sustainability, Technology and Humanism (STH), UPC

6.2.5 Anàlisi de dades

Les dades que fonamentaran la solució que respongui als problemes i qüestions plantejats a l'inici de la Tesi (de quina manera introduir de forma eficient la Td a la formació en enginyeria per a la SB) s'obtindran des de diverses fonts d'informació:

- Bibliografia (llibres, revistes, webs)
- Entrevistes amb experts
- Activitats educatives
- Congressos i seminaris
- Mapes conceptuals
- Questionaris

6.2.6 Temporalització

La següent taula mostra la temporalització prevista de les tasques descrites en l'apartat anterior.

	2013					2014											2015										
Activitat	J	S	O	N	D	G	F	M	A	M	J	J	S	O	N	D	G	F	M	A	M	J	J	S	O	N	D
Recerca bibliogràfica	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Congressos i activitats educatives		■	■			■	■						■	■	■					■							
Identificació d'experts i definició de les activitats de contacte	■	■	■	■																							
Definir indicadors i correlacions		■	■	■																							
Dissenyar enquestes (qüestionaris i mapes conceptuals) i entrevistes			■	■	■	■																					
Realitzar entrevistes				■	■	■	■	■	■	■	■	■															
Realitzar enquestes				■	■	■	■	■	■	■	■	■															
Recopilació de la informació											■	■	■	■	■	■											
Anàlisi de la informació													■	■	■	■	■	■	■	■							
Conclusions																					■	■	■				
Redacció Tesi															■	■	■	■	■	■	■	■	■	■	■		
Defensa Tesi																										■	■

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