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Master of Science

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Master Thesis

Appealing to an inter/transdisciplinary attitude: who is doing what in research centers working on urban sustainability?

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Acknowledgments

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Abstract

Inter/transdisciplinary (ITD) approaches are key to cope with current societal problems, characterized by increasing volatility, complexity and uncertainty. However, such ITD strategies are difficult to be implemented in current research design, for the bureaucracy and the rigid structure of the academic community and the silos, competitive culture inside research centers. The present thesis seeks to enlarge the understanding about how to implement ITD approaches in research centers focusing on urban sustainability, how they can measure their ITD performance, their cooperation strategies, and what are the challenges associated with ITD. To this aim, a sample of 23 ITD research centers, mostly located in Europe, was selected and studied through the information available on their websites (n. of members, gender balance, years of foundation, mission, funding, etc.) and the results of semi-structured interviews performed with members of such institutions. A preliminary extensive study of the emergent literature about ITD has been performed to track down which criteria are currently suggested by the theory of organizational management to implement ITD approaches. Those findings have been compared with in the quantitative and qualitative data collected about the centers, to understand gaps between theory and practice of ITD and suggest success/failure indicators for inter/trans-disciplinarity. Our work shows a relation between the barriers that researchers find on their work (structural, communicational, budgetary) and the lack of common agreement on policies, as well as the lack of a legitimate and recognized role of ITD specialists within the university. Conclusions provide policy recommendations for the research centers willing to achieving more effective and efficient ITD research, and contribute to the standardization of ITD performance measures giving more hints on new indicators of success/failure in ITD research centers.

Keywords: interdisciplinary, transdisciplinary, research, indicators, measures, decision making.

Introduction

The need for ITD research

Increasingly, there are more and more calls for more interdisciplinary approaches to problems, along with encouragement for greater collaboration and networking among institutions and researchers (Hicks and Katz, 1996). In this early statement, more than 20 years ago Hicks and Katz already noted the need for an approach different from discipline-based in problem solving on research. Also, they mentioned a key point recurrent in the literature: interdisciplinary studies are problem driven.

When looking for the motivation of this call, it is found that such encouragement is often based on the assumption that interdisciplinary research will contribute to more effective innovation and enhanced competitiveness. Pressure to encourage interdisciplinary research also comes from the need to solve complex socio-scientific problems, where one discipline on its own cannot provide an answer (Bruce *et al.*, 2004).

This perception that there are domains where the mono-disciplinary knowledge is not sufficient to provide complete answers is recurrent in the literature. Nadine Rons asserts that the idea that the current structural disciplinary organization hampers potentially valuable and innovative interdisciplinary interactions is widely accepted. (Rons, 2011)

> *"Each field of study has its own lens on the world and its own toolkit for interpreting observations. None, however, have a monopoly on which questions are most important as they relate to other disciplines." (Glod, 2016)*

Leading institutions claim that many of the complex problems society is currently facing (e.g. in the area of health care, mobility or the environment) demand innovative solutions that combine knowledge from different scientific disciplines (Sciences, Engineering and Medicine, 2005).

As can be sees, many authors and organizations have been pointing at the need for more interdisciplinary approaches for more than 30 years. Thus,

inter/transdisciplinary centers started to show and today there are many universities that have that kind of centers, as well as independent and institutions that operates with these approaches.

Thesis objective

Despite the worldwide diffusion of inter/transdisciplinary method, the present work begins with the assertion that it is still difficult to achieve an effective and efficient inter/transdisciplinary work.

The present thesis in aimed to enlarge the literature of studies of inter/transdisciplinary centers to deepen the understanding of how to achieve efficient and effective inter/transdisciplinary research and education, and thus make a contribution to the setting, in the future, of standardized guidelines for universities and research centers that are willing to apply this methodology. The focus will be on study the success/failure indicators under which this research is to be evaluated in order to cover all its attributes, barriers that hinder the opportunities of ITD research and factors that encourage such research.

This work was done as a collaboration with TrUST - Transdisciplinarity for Urban Sustainability Transition – project, studying the state of contemporary centers performing inter/transdisciplinary research and education. Because of that, both objectives are aligned. TrUST is a research project that aims at better understanding of how to achieve more efficient and effective inter/transdisciplinary research (ITDR) and education for urban sustainability transitions.

A sample of 23 research and education centers self-defined as inter/trans disciplinarity has been selected to perform the analysis, aimed broaden the understanding on some of the following triggering questions:

**What are the factors that encourage interdisciplinary research?*

**What is the more accurate way to evaluate ITDR?*

**Which policies should be applied to enhance ITDR?*

*Which are the most common barriers faced by ITDR centers?

The final aim is to understand which are the factors that determine the success or failure of inter/transdisciplinary research, and with base on that provide as a conclusion some policy recommendations for centers to track and improve those factors.

Theoretical prerequisites

Before we go further in the analysis of the success/failure indicators and factors that enhance or harm inter/transdisciplinary research, we have to make a stop to clarify some concepts and provide some definitions.

Many times, in the present and in different papers, the terms interdisciplinary and transdisciplinarity are treated as synonyms, but they are not (Jensenius, 2012). Even if many centers use one or another term indifferently, some authors have pointed it differences and it is important to highlight them before starting to present further definitions and concepts on this topic.

In 2012, based on the paper "Advancing the social sciences through the interdisciplinary enterprise" (Stember, 1991), Alexander Jensenius draft definitions of what inter and trans-disciplinarity mean by contrasting them with all the other "disciplinarities" (Jensenius, 2012).

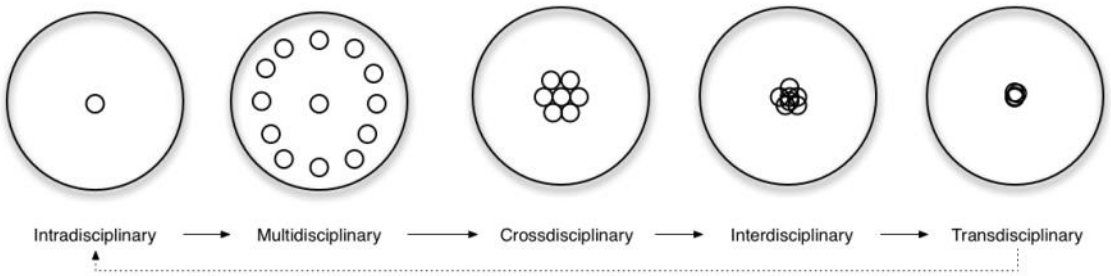

Figure 1 - Disciplinarities (Alexander Jensenius, 2012)

Intradisciplinarity: occurring within the scope of an academic discipline or between the people active in such a discipline. Interactions under this methodology do not usually show lack of communication because teams

share a common language, culture and similar backgrounds. This kind of research collaborations is commonly seen in basic disciplines (relatively autonomous and primarily aim to develop fundamental knowledge about matter, life or the universe) such as physics and chemistry, and the amount of disciplinary research collaboration is positively related to academic rank (Van Rijnsoever and Hessels, 2011).

Multidisciplinarity: adjective for combining or involving several academic disciplines or professional specializations in an approach to a topic or problem (Oxford dictionary). Multidisciplinary activities draw upon insights from two or more disciplines. Unlike interdisciplinary and transdisciplinary activities, though, multidisciplinarity simply juxtaposes these insights and does not attempt to integrate them. Multidisciplinarians are also less likely to critically evaluate the insights they draw upon (Szostak, 2015).

This concept begins to get closer to the notions of interdisciplinarity and transdisciplinarity, but there is a fundamental difference: people from different disciplines working together, but each providing their own disciplinary knowledge (Jensenius, 2012). The second part of the sentence is interesting because it distinguishes the way that interactions are carried out: each researcher provides insights from the viewpoint of his/her discipline, each discipline makes its own contribution, not involving itself in other's domain and not concerned about integration of cultures or create shared-knowledge.

Crossdisciplinarity: Viewing one discipline from the perspective of another; for example, the physics of music and the history of math (Jacobs, 1989). At this stage of research, scientists are interested in understanding the others disciplines' viewpoints. Still making contributions by their own field but trying to understand a bit better the big picture. Lot of interaction and cross fertilization characterize this collaboration.

An alternative definition provided by (Szostak, 2015) states that cross-disciplinary is a general term used to refer to any activity that involves two

or more academic disciplines. These activities can range from those that simply place disciplinary insights side-by-side (Multidisciplinary) to much more integrative or socially inclusive approaches.

Interdisciplinarity: integrating knowledge and methods from different disciplines, using real synthesis of approaches (Jensenius, 2012). At this stage is where the boundaries of disciplines start to merge. Teams share methods and vocabulary with the aim to create a new form of knowledge, shared knowledge, which does not belong to any single discipline but to the mix. Interdisciplinary research collaboration is defined as: "the collaboration between scientists from different disciplines with the goal of producing new knowledge."(Van Rijnsoever and Hessels, 2011). Generally, a team provide similarly approaches to an issue from a range of disciplinary perspectives but in this case the contributions of the various disciplines are integrated to provide a holistic or systemic outcome (Bruce *et al.*, 2004).

Transdisciplinarity: Beyond the scope of the disciplines; that is, to start with a problem and bring to bear knowledge from the disciplines (Jacobs, 1989). Creating a unity of intellectual frameworks beyond disciplinary perspectives. At this level, shared knowledge is created and the contributions of the scientists, even if still biased by their academic backgrounds, does not necessarily come from their former disciplinary perspective but from the knowledge created and learnt within the team. This bias is represented graphically by the fact that circles are not fully merged, and so knowledge is not one hundred percent common; when this happens, a new discipline is created, just as it occurred with biochemistry or biotechnology.

Narrow definitions of interdisciplinarity and transdisciplinarity have been given. Still, there is a little agreement on the scientific community on those and other concepts that surround inter/transdisciplinary research. Moreover, the way research centers perform interdisciplinarity are not the same. Disagreements about definition reflect differing views of the purpose of research and education, the role of disciplines, and the role of critique (Klein, 2005).

Note: the definitions given of interdisciplinarity and transdisciplinarity aim to provide preliminary understanding of these concepts. Further analysis on the diversity of definitions is given in “Definition(s)” section.

Even if establish common definitions on the terms mentioned on the present section is considered necessary, in alignment with the understanding of TrUST project, it is worth mention that some authors consider it misleading. Sheila Jasanoff considers that avoiding often confused debates around terms such as inter-, multi, and trans-disciplinary is necessary to focus the discussion on how to represent ID, problematizing the notion of a “discipline” and stressing political dimensions of challenging disciplinary configurations (Jasanoff, 2013).

The present thesis does not pretend to provide arguments against disciplinary research and education. Disciplinarity and interdisciplinarity can coexist and feedback each other. Disciplines provide crucial knowledge, methodologies, and tools for interdisciplinary and transdisciplinary work. However, in many discussions, disciplines are still treated uncritically as monolithic constructs. Studies of disciplinarity reveal that disciplines exhibit a striking heterogeneity, and that boundary crossing has become a marked feature of contemporary research (Klein, 2008).

For the scope of this work, and in accordance with the current diffusion of these terms in the literature, in what follows, the terms interdisciplinary and transdisciplinary will be used alternatively and usually interdisciplinarity will be considered to comprehend in transdisciplinarity, as suggested by Klein:

> *“Transdisciplinarity is a specific form of interdisciplinarity that, while recognizing the invaluable contribution from different scientific fields, also emphasizes the need for cooperation and communication among the various parts of society with these academic disciplines in order to meet the complex challenges we face today.”*
>
> *(Klein et al., 2001)*

Research scope

Many studies (Bruce *et al.*, 2004; Sciences, Engineering and Medicine, 2005; Klein, 2008) point that in numerous cases the research atmosphere hinders the endeavors of scientists to incorporate inter/transdisciplinary research approaches.

Taking as a point of departure the hypothesis that one factor that could help to overcome that barriers is to set standardized procedures, policies and measures for research and education centers that are willing to engage in a more inter/transdisciplinary work.

To make a step further in attaining this aim, a set un evaluation procedures and measures in detailed, which track may enhance the efficiency and efficacy of inter/transdisciplinary research. These procedures are given in the context of a series of policy recommendations.

Limitations

There is a lack of understanding regarding the optimal conditions for interdisciplinary research (Van Rijnsever,2011). This work aims to enlarge the present literature on case studies and provide an insight about the conditions that favor interdisciplinary research, but there is still a long way ahead and lot of groundwork has to be done to stablish a widely-accepted set universal guidelines to interdisciplinary research.

Further, as said before, the context-dependence feature of this kind of research must be always taken into account and that is why we must be very careful when giving advices. Advices provided to one center may be not applicable on all of them, or even in the same center but in different conditions.

Another considerable limitation of our study is, as shown in figure 2, that most of the centers that compose the sample are located in Europe. This fact may imply that generally, the variables analyzed have a similar socio-economical context, and then any conclusion made might be biased with a European cosmovision.

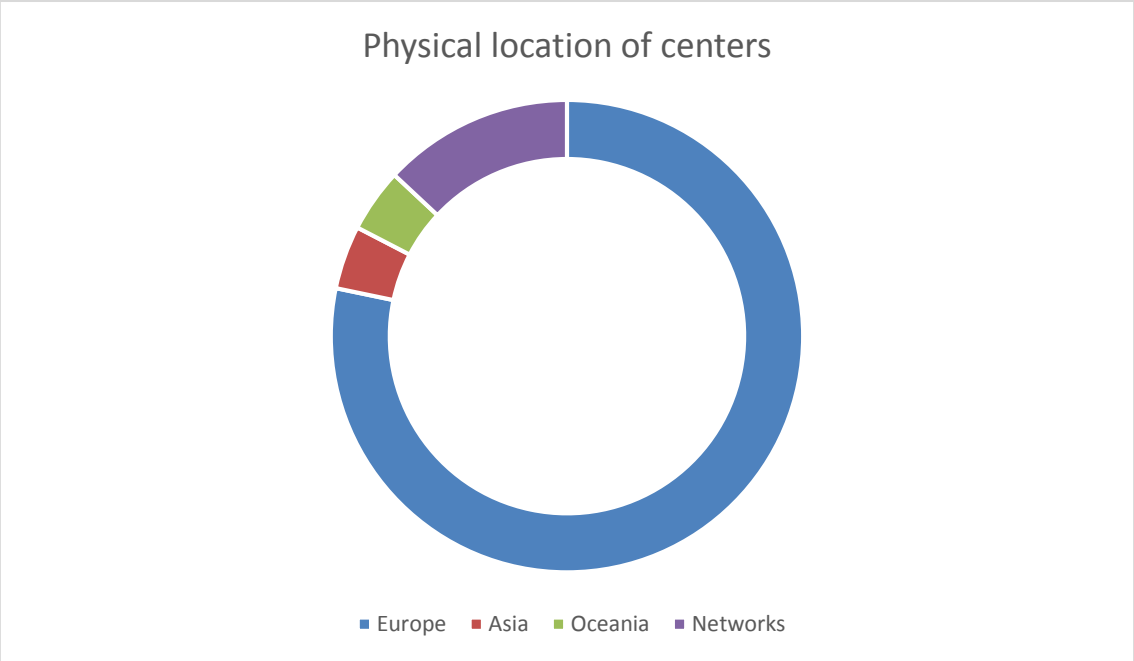

Figure 2 – Physical distribution of centers

Added, a different limitation of our study is that its results may not be applicable to some areas of inter/transdisciplinary research because an intentional bias in the selection of the centers. As the focus of the study of TrUST organization are urban sustainability transitions, this topic and labs addressing it may be overrepresented with respect to other areas of knowledge in the sample.

Methodology

The present document was performed in the context of a bigger investigation being performed by TrUST collaboration project. TrUST - Transdisciplinarity for Urban Sustainability Transition - is a research project that aims at better understanding how to achieve more efficient and effective inter/trans-disciplinary research and education for urban sustainability transitions.

With this in mind, TrUST team selected 23 self-declared inter/transdisciplinary research centers mostly located in Europe and performed interviews with members, heads, chairs, coordinators of each center in order to understand how they work, how they map their activity, how they define/understand inter/transdisciplinarity, what triggering factors they face when working in that way, how they measure they results, how are they evaluated, etc.

The selection of the centers of the sample was done by the experts of TrUST project through the focus group methodology. Focus group methodology is a qualitative research tool that is frequently used in social sciences to depict the meanings, ways of understanding or experiences related to a complex phenomenon (Lunt and Livingstone, 1996). This methodology typically involves a series of team meetings to determine how to proceed about a given topic, usually guided by a moderator.

Taking as a departure point that list of 23 research centers, the work of the candidate consisted in carry out a web investigation of that centers. Inspecting the webpages of each one of the research institutions and the corresponding universities and affiliations with, the candidate collected quantitative information such as mission, foundation year, physical location, SDG (Sustainable Development Goals) alignment, and composition of the centers (gender, academic progress) summed to both qualitative and quantitative data gathered from the interviews.

The information collected was contrasted with the emergent literature of the topic and centers have been compared in several excel files looking for similarities and differences, trying to understand which are the factors

that determine their success or failure, and always keeping the focus in the triggering questions:

**What are the factors that encourage interdisciplinary research?*

**What are the more accurate indicators to evaluate ITDR?*

**How to measure the outputs of applying ITDR? What outputs should be expected?*

**Which policies should be applied to enhance TIDR?*

**Which are the most common barriers faced by ITDR centers?*

Shown below, the list of the 23 centers analyzed:

- Future of Urban Legacy Lab (Polytechnic of Turin)
- RESTORE COST action project - EURAC
- Ersilia Foundation
- Instituto per la Ricerca Sociale
- Sustainability Science Lab (University of Melbourne)
- Architecture & Climate Lab (Catholic University of Louvain)
- Sustainability Unit (Hong Kong University of Science and Technology)
- INTERPID COST action - Institute for Higher Science Education (University of Lisbon)
- Centre for Studies of Sustainable Energy (Norwegian University of Science and Technology)
- Euskampus Foundation (University of Basque Country)
- Gothenburg Center for Sustainable Development (University of Gothenburg)

- Cambridge Institute for Sustainability Leadership (University of Cambridge)
- Transport Economy Planning Laboratory (University of Lyon)
- ALICE (Federal Institute of Technology in Lausanne)
- SIRIS Academic Consultancy
- Institute of Social Sciences (University of Lisbon)
- Research and Transfer Centre "Sustainability and Climate Change Management (Hamburg University of Applied Sciences)
- Innovation and Community Unit (Polytechnic University of Catalonia)
- Center for Logistics and Innovative Production (University of Gävle)
- Multi-Actor Systems Department (Delft University of Technology)
- Urban Resilience Research Network (International University of Catalonia)
- ABUD
- Department of Geography (University of Zagreb)

Figure 3 – Physical location of centers

As anticipated, the vast majority of the research and education centers being studied are located in Europe, with the exception of one in the Hong Kong University of Science and Technology, and another in Melbourne, Australia. There are three also networks that works in a decentralized way and without border limits, but still the majority of their activity lies within European limits.

Some of the questions of the semi-structured interview are the following:

> *Would you define your lab as inter/trans/multi-disciplinary?*
>
> *Why the collaborative effort was initiated, and what expectations they had about the collaborative process before doing it?*
>
> *How was the process that brought your centre to inter/trans/multi-disciplinary?*
>
> *How do you make ITDR happen? Which methods, social technologies, tools and tricks (communication strategies) you put in place?*
>
> *What are the triggering factors for ITD work?*
>
> *What are the barriers you encountered in ITD work?*
>
> *Is your ITD performance evaluated? How? And what do you think about it?*
>
> *What are the current challenges/opportunities for more effective ITD work in your lab?*

The selection of the literature analyzed was done with the support of experienced professionals of the field; members of TrUST organization with experience on such productions and graduate students with pertinent backgrounds.

Usually, every research center has very rich websites and a lot of available information, including a sheet where they detail their directories, from where information was gathered such as gender composition and information regarding number of professors, students, administrative

stuff, etc. Nonetheless there are some data missing due to the lack of update on certain centers' webpages or the fact that they simply do not publish that kind of information. Still, the data gathered is large enough to be analyzed and identify trends.

The choice of the categories in which centers are compared to each other was not venturous either. It was carried out after a carefully look at contemporaneous literature on the topic. For instance, the analysis of the gender composition is suggested by Frank J. Van Rijnsoever (Van Rijnsoever and Hessels, 2011), who found that female scientists are more engaged in interdisciplinary research collaborations. Thus, we stablish the female-hiring as one of the factors that favor successful interdisciplinary collaborations.

The criteria for the selection of the categories under which centers and compared, as well as the contrast between literature and practical results will be presented as the categories are developed.

Literature Review & Results

Definition(s)

As explained, there is not an outstanding common agreement on definition of concepts regarding ITDR. Moreover, no single definition is likely to encompass the diverse range of activities that have been described under the heading of interdisciplinary research (Sciences, Engineering and Medicine, 2005).

As the objective of this thesis is to contribute to the standardization of ITD performance measures and suggested policies, it is worthy to advance in a previous step that is to attain some agreement in the definition of interdisciplinarity and transdisciplinarity.

To shed some light on this issue, a series of definitions from the literature were selected to provide a variety of perspectives that will enrich our understanding of interdisciplinarity (see Table 1).

As can be seen in this cluster of definitions, even if they are diverse and different authors put the focus on different aspects. Interdisciplinarity has been variously defined in this century: as a methodology, a concept, a process, a way of thinking, a philosophy, and a reflexive ideology (Klein, 1990). Moreover, all interdisciplinarities are not the same. Disagreements about definition reflect differing views of the purpose of research and education, the role of disciplines, and the role of critique (Klein, 2005). Despite that, there are key concepts that are recurrent, and we can find similarities and common patterns among then. Cutting across all these theories is one recurring idea. Interdisciplinarity is a means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches (Klein, 1990).

Integration is a concept of central importance and it is mentioned in the majority of the definitions and broadly in the literature (Klein and Newell, 1997; Qin, Lancaster and Allen, 1997; Bruce et al., 2004; Rhoten and Pfirman, 2007; Klein, 2008). In the pursue of this work for contributing to standardization of concepts surrounding interdisciplinarity, the fact that

the majority of authors agree upon the central importance of this concepts is an important finding.

Source	Definition	Focus
(Rhoten and Pfirman, 2007)	"Interdisciplinary refers to the integration or synthesis of two or more disparate disciplines, bodies of knowledge, or modes of thinking to produce a meaning, explanation, or product that is more extensive and powerful than its constituent parts"	Integration Knowledge production
(Baber *et al.*, 1995)	"Interdisciplinarity is characterized by the explicit formulation of a uniform, discipline transcending methodology or a common methodology"	Discipline formulation Common methodology
(Qin, Lancaster and Allen, 1997)	"the integration of disciplines within a research environment"	Integration Research
(van Raan and van Leeuwen, 2002)	"Typical interdisciplinary research is based on many different fields, each having their own community"	Different fields Different views
(Klein and Newell, 1997)	"A process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession… [It] draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective"	Problem solving Complexity Integration
(Barry and Born, 2013)	"Interdisciplinarity should be thought as […] an array of programmatic statements, policy interventions, institutional forms, theoretical statements, instruments, materials and research practices […] that enact a variety of interrelations between disciplines."	Practice-oriented Interrelations Different fields

Source	Definition	Focus
(Lang *et al.*, 2012)	"Transdisciplinarity is understood as a reflexive, integrative, method-driven scientific principle in many of the publications we analysed, with an emphasis on solving societal problems by integrating knowledge from various scientific and social bodies of knowledge".	Method-driven Scientific principle Problem solving Integration Different fields
(Van Rijnsoever and Hessels, 2011)	"the collaboration between scientists from different disciplines with the goal of producing new knowledge."	Collaboration Different fields Knowledge production
(National Academy of Science, 2005)	"Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice."	Mode of research Integration Different fields Knowledge production Problem solving

Table 1 – Classification of ID definitions. Based on Baptista *et al.*, 2019)

Integration is not a strictly linear process, either in education or in research. To achieve integration at academic level means to find the appropriate balance between traditional disciplinary lectures and interdisciplinary approaches. Most interdisciplinary programs use a

combination of disciplinary courses, multidisciplinary formats, and interdisciplinary elements and approaches (Klein and Newell, 1997).

Among the many classifications that are given in the literature to organize the variety of definition, one that fits with the scope of this work is the one offered by the team of SHAPE-ID, an organization aimed to address the challenge of improving interdisciplinary cooperation between the Arts, Humanities and Social Sciences and Sciences, technology, engineering and mathematics in Europe. In their report "Literature Review on Understandings on interdisciplinary and transdisciplinary research" they propose the following classification to handle the diversity of definitions of interdisciplinarity and transdisciplinarity (Baptista *et al.*, 2019).

"In the academic literature, IDR and TDR are considered as:

*1. An **object** of conceptual and empirical investigation: this demands the co-construction of concepts;*

*2. A **method** of working: this understanding requires the traceability of processes;*

*3. A **phenomenon** subject to historical and geographical variation: this justifies the mapping of understandings."*

(Baptista *et al.*, 2019)

Drivers

In the quest for contributing the standardization of indicators of success and failure and evaluation criteria for inter/transdisciplinary work, studying the drivers and motivations of institutions and contrast them with the emergent literature will enlarge the understanding needed to depict under what criteria inter/transdisciplinary centers are to be evaluated to successfully assess their exercise.

Interdisciplinary and transdisciplinary research are not driven by a single goal (Klein, 2008). By looking at the interviews performed it was found that the drivers and the triggering factors of inter/transdisciplinary

research vary within the institutions performing it. The motivations vary from embrace knowledge sharing and co-creation (Ersilia Foundation) to promote environment-friendly energy technologies (Centre for Studies of Sustainable Energy). Most recurrent drivers mentioned in the literature will be explained in this section, and contrasted motivations and missions of the sample of centers.

A first insight to tackle this question is provided by the National Academic of Science (Sciences, Engineering and Medicine, 2005): they provide four kinds of motivation or "drivers" present of interdisciplinary projects. The four drivers are listed below in table 2, which also shows a brief explanation or description, and examples in the third column.

Driver	Description	Examples
The inherent complexity of nature and society	Human society in its natural setting contends with enormously complex systems that are influenced by myriad forces. A full predictive or even descriptive understanding requires the use of many disciplines.	Climate change, Antarctic ozone hole, the international geosphere/biosphere program, human-genome mapping
The drive to explore basic research problems at the interfaces of disciplines	Some of the most interesting scientific questions are found at the interfaces between disciplines. Exploring such interfaces and interstices leads investigators beyond their own disciplines to invite the participation of researchers in adjacent or complementary fields and even to stimulate the development of a new interdisciplinary field.	Biochemistry, cognitive science, biology and mathematics/statistics, ecology and economics (and other social sciences)
The need to solve societal problems	Human society depends more than ever on sound science for sound decision making. The fabric of modern life is held together largely by techniques and tools of science and technology. But the application of technologies to enhance the quality of life can itself create problems that require technological solutions.	Greenhouse gases, artificial fertilizers, nuclear power generation.
The stimulus of generative technologies	Generative technologies are those whose novelty and power not only find applications of great value but also have the capacity to transform existing disciplines and generate new ones.	The microscopes of Hooke, the development of the internet, magnetic resonance imaging.

Table 2 – Drivers for ID projects (Sciences, Engineering and Medicine, 2005)

Notwithstanding, as we see very often in the literature of this topic, there's not a common agreement on these drivers and there are authors that provide others. For instance, on the other hand Ann Bruce et al. provided their own vision of the motivations or "modes" for conducting interdisciplinary research; in this case there are two fundamentally different:

Mode 1 ITD	Brings together researchers from different disciplines in order to overcome a blockage to further development within a discipline, or to enable the discipline to move into new and productive areas of research.
Mode 2 ITD	Mode 2 Interdisciplinary Research addresses issues of social, technical and/or policy relevance where the primary aim is problem-oriented and discipline related outputs are less central to the project design.

Table 3 – Modes for ID projects (based on Bruce et al., 2004)

Further analysis about the motivations that leads to interdisciplinary practices is provided by (Klein and Newell, 1997). Based on the results of an international survey performed by the Organization for Economic Cooperation and Development, they did their own investigation and give motivations for interdisciplinary study:

- General and liberal education
- Professional training
- Social, economic and technological problem solving
- Social, political and epistemological critique
- Faculty development
- Financial exigency (downsizing)
- Production of new knowledge

(Klein and Newell, 1997)

Moving to the analysis of the data gathered, each researcher interviewed was asked to provide his/her own attestation about the drivers that lead his/her professional interdisciplinary research and the triggering factors for ITD work. Unfortunately, conclusive results have not been extracted from the analysis of the answers regarding the triggering factors of the

respondents for doing inter/transdisciplinary research. There was not sufficient strong trends or similarities to assert precise results.

Missions

Moving forward to enlarge the understanding of the motivations of each institution in engaging in interdisciplinary research, now the focus turns to the analysis of their missions. The information studied in this section was collected from the websites of the centers.

Out of the 23 centers being analyzed, 21 specifically declare their mission on the website and thus those centers are comprehended in the following breakdown. When looking for similarities in the missions, interesting findings has been done.

Figure 4 – Mission topics

The figure 4 gives us fundamental information of the motivation of the centers. As shown, important similarities have been found. Among the most mentioned motivations we acknowledge advance fundamental understanding, knowledge sharing, education, public policies and address problem. The selection of the categories was done with base on the literature review; each topic analyzed from the mission of the centers was

proposed for academic authors as to be the motivations for inter/transdisciplinary research.

For adding another valuable insight about the data analyzed, the table 5 shows the percentage of the center sample (in this case 21) that declare to pursue the pertinent subject in their mission.

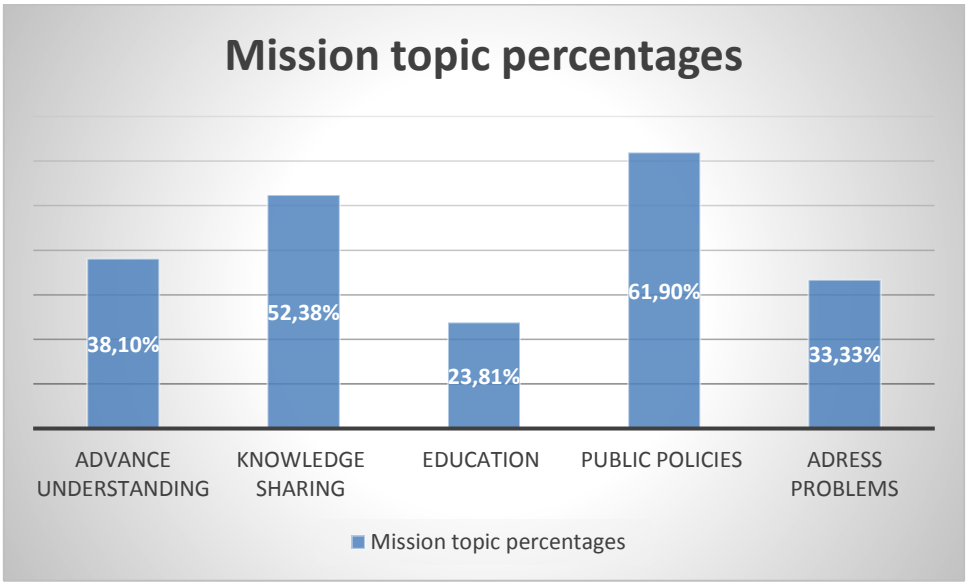

Figure 5 – Mission topics percentages

As can be better appreciated in this figure, all the topics selected pointed out more than a 20% in the sample of missions. Below, each category selected for analyze the missions will be explained together with its relevance to inter/transdisciplinary research and education.

Advance fundamental understanding and knowledge production

The first topic we found significantly repeatedly in the sample of mission statements is the one of advance fundamental understanding and produce new knowledge. It is proposed by the National Academy of Science (Sciences, Engineering and Medicine, 2005) as to be one of the drivers for interdisciplinary research. It is mentioned in the mission of 8 out of the 21 centers being analyzed in this section (38.1%). The table 4 shows passages from the missions' sample in which centers refer to the aim of advance fundamental understanding.

Center	Mission fragment
Future Urban Legacy Lab	"FULL main aims are to bridge knowledge of the past and visions for the future in the urban realm."
RESTORE COST Action	"Jointly develop their own ideas and new initiatives across all fields in science and technology." (COST)
Ersilia Foundation	"Embrace knowledge sharing & co-creation…"
Instituto per la Ricerca Sociale	… "using theories, methodologies and analysis techniques to produce new knowledge"
Sustainability Unit (HKUST)	"The Division strives to foster collaboration among students and faculty members, enabling them to address relevant science…"
INTERPID COST Action	"understand how to achieve more efficient and effective interdisciplinary research in Europe…"
Institute of Social Sciences (University of Lisbon)	…" for enhancing the social relevance of knowledge produced by ICS."
Research and Transfer Centre "Sustainability and Climate Change Management" (FTZ-NK)	"The main objective of the FTZ-NK is to support fundamental and applied research on sustainable development and climate issues…"

Table 4 – "Advance fundamental understanding" arguments in missions

Knowledge production has shifted towards IDR in the context of application, problem solving and greater collaboration (Starkey and Madan, 2001). In addition, Sheila Jasanoff states that declares interdisciplinarity can define new territories of intellectual creativity characterized by questions and answers not previously recognized as necessary or desirable (Jasanoff, 2013).

Knowledge sharing

Continuing our analysis, the next coincidence is the second most weighted topic, and it is the category of knowledge sharing, encompassing concepts such as network, sharing, alliances, collaboration and cooperation. Allusions and mentions to collaborative drivers of the work have been done in 11 (52.4%) of the mission statements. The table 5 shows extracts from the missions that give an idea of how centers approach knowledge sharing and networking activities.

Center	Mission fragment
Future Urban Legacy Lab	… Research activities are based on cross- and interdisciplinary methods; **collaboration** and experimentation …
RESTORE COST Action	Jointly develop their own ideas and new initiatives […] through pan-European **networking** of nationally funded research activities.
Ersilia Foundation	Embrace knowledge sharing & co-creation, and […] promote knowledge **alliances** among universities, research centers and schools.
Instituto per la Ricerca Sociale	For IRS, doing research essentially means using theories, methodologies and analysis techniques to produce new knowledge to be made **available to everyone**.
Sustainability Unit (HKUST)	The Division strives to foster collaboration among students and faculty members…
INTERPID COST Action	INTERPID is a 32-country **network**…
Euskampus Foundation	… carrying out joint training, research and **knowledge transfer** and dissemination actions.
Gothenburg Center for Sustainable Development	The core task of Gothenburg Centre for Sustainable Development (GMV) is to **facilitate cooperation** …
Cambridge Institute for Sustainability Leadership	… focused **collaboration** between business, government and finance institutions, to deliver positive outcomes for people and environment in pursuit of the UN Sustainable Development Goals (SDGs).
Research and Transfer Centre "Sustainability and Climate Change Management" (FTZ-NK)	… Furthermore, the centre will promote the contribution of the HAW Hamburg to knowledge and technology **transfer** on a national and international level.
Urban Resilience Research Network	The final aim is to provide a virtual space for discussing and **disseminating** the advances of a more critical approach to resilience, linking it to sustainability and social justice.

Table 5 – "Knowledge sharing" arguments in missions

This heavy coincidence reveals one of the key characteristics of the interdisciplinary research: its collaborative nature. Nearly 20 years ago, Scholz & Marks (Scholz and Marks, 2001) have already acknowledged that organizing collaborative learning networks between science and society is one of the key components of inter/transdisciplinary approaches. The

results presented provide evidence that reaffirm the statements they made.

In addition, as sociologists of science have shown, science is a social institution where advances depends crucially on interaction with other scientists (Katz and Martin, 1997). In this document it can be seen how the second mission's topic we selected from the literature is closely related with the first one at the same time that provide wider insights.

Collaboration can occur in smaller contexts, as it occurs in the case of Sustainability Unit in the Hong Kong University of Science and Technology, where foster collaboration between students and faculty members within a bigger institution that is the University; or it can occur in bigger contexts, such as in the INTERPID COST action where scientists work in a 32-country network that includes different laboratories and institutions.

Despite that, what is clear is extent to which centers pursue collaboration and knowledge sharing. The results provided in this section confirms what was found in the theory: The essence of the collaborative work often characterizes the concepts of interdisciplinarity (Aboelela *et al.*, 2007).

Education

Moving on, the next topic to analyze is education. This motive is pointed out in 5 out of the 21 missions (23.8%). The table 6 provide fragments of the missions that works as examples to understand how they approach training and educational goals.

The literature provides several suggestions of the educational purpose of inter/transdisciplinarity. For instance, general and liberal education was one of the origins or motivation of interdisciplinary study proposed by Klein and Newell in 1997, as shown in the previous section

Center	Mission fragment
Ersilia Foundation	Organize innovative **training** school […] and to transfer and increase knowhow to all levels of **educational** areas.
Sustainability Unit (HKUST)	The Division strives to foster collaboration among students and faculty members, enabling them to address relevant science, technology and policy issues in environmental **education**.
Euskampus Foundation	… carrying out joint **training**, research and knowledge transfer and dissemination actions.
SIRIS Academic Consultancy	We are a European consulting firm designing and implementing strategy and policy solutions for **higher education**, research and innovation.
Institute of Social Sciences (University of Lisbon)	provided a stimulus for innovative and interdisciplinary research, for **high-quality teaching** and for enhancing the social relevance of knowledge produced by ICS.

Table 6 – "Education" arguments in missions

The key role of interdisciplinarity education started with the proliferation of university-industry collaborations in the last decades (Sciences, Engineering and Medicine, 2005). Understanding the interests of both partners in those collaborations is important when defining the characteristics of the association to ensure that the objectives of both of them are well represented. In the case of US in the decade of 2000, collaborations between academe, industry and the government yield substantial benefits for all partners (Sciences, Engineering and Medicine, 2005). Academe-industry collaborations shows how this third topic of the centers' missions is related with the previous one, knowledge sharing.

Public policies

Continuing the analysis, the next fundamental topic of our study is the aim of centers to support public policies and decision-making. Leading institutions claim that many of the complex problems that society is currently facing demand of innovative solutions that combine knowledge from different scientific disciplines (Sciences, Engineering and Medicine, 2005): "human society depends more than ever on sound science for sound decision making".

Further studies on the relation of transdisciplinary research and policy was done by Pohl, Christian. In his paper he studied transdisciplinary research as a way to bridge science and policy (Pohl, 2008). To illustrate this link, he explained how in the early 1990s a number of European environmental research programs worked as a bridge with policy.

Thus, policy making was included as one of the key drivers of inter/transdisciplinary research. Results confirm the crucial importance that the National Academy of Science and Pohl give to this topic: 13 out of the 21 missions of the sample (61.9%) state that their work is related with public policies and support decision making. The table 7 shows the quotes of the missions with such statements to exemplify how the centers approach this topic.

Center	Mission fragment
Future Urban Legacy Lab	FULL main aims are to bridge knowledge of the past and visions for the future in the urban realm […] to support **decision-making processes**.
Instituto per la Ricerca Sociale	We consider research and development of knowledge fundamental to improve the effectiveness of **public policies**.
Sustainability Unit (HKUST)	The Division strives to foster collaboration among students and faculty members, enabling them to address relevant science, technology and **policy issues** in environmental education.
Centre for Studies of Sustainable Energy	CenSES' research objective was to conduct research that **supported public and private decision makers** in strategic decisions and policies that could promote environment-friendly energy technologies.
Gothenburg Center for Sustainable Development	… to facilitate cooperation with the aim to generate and **practically implement knowledge** about sustainable development.
Cambridge Institute for Sustainability Leadership	… collaboration between business, **government** and finance institutions, to deliver positive outcomes for people and environment.
LAET (laboratoire aménagement économie des transports)	… evaluate transport and land use **policy** ; and provide **decision-support** to stakeholders seeking solutions to current critical issues facing society.
ALICE (Atelier de la Conception de l'Espace)	Projects on **public space** and the interior of the city and human habitat serve as a point of departure for in-depth research…

Center	Mission fragment
SIRIS Academic Consultancy	We are a European consulting firm designing and implementing strategy and **policy solutions** for higher education, research and innovation.
Research and Transfer Centre "Sustainability and Climate Change Management" (FTZ-NK)	The main objective of the FTZ-NK is to support fundamental and **applied research** on sustainable development and climate issues, especially by conducting **practice-oriented** research projects.
Multi-Actor Systems Department (MAS)	MAS addresses the question of how, in such an environment, **decision-making**, change and coordination of and in socio-technical systems happen.
Urban Resilience Research Network	The final aim is to provide a virtual space for discussing and disseminating the advances of a more critical approach to resilience, linking it to sustainability and **social justice**.
ABUD	We support architects, developers and decision makers to create a resilient and liveable built environment.

Table 7 – "Public policies" arguments in missions

As detailed in the previous section, this topic was also acknowledged by Klein and Newell as one of their motivations for interdisciplinary study.

Problem Solving

The next factor that appears repeatedly in our mission analysis is the aim of address problems, challenges and/or solutions. This encouragement factor is mentioned in 7 out of the 21 missions (33.3%). Table 8 provides fragments of the mission statements to favor the understanding on how centers approach problem-solving research.

As well as the previous ones, this topic reflects other of the key characteristics of contemporary inter/transdisciplinary research: the problem orientation. The problem-driven feature of interdisciplinary research is one of the most mentioned drivers in the emergent literature (Starkey and Madan, 2001; Jeffrey, 2003; Hackett and Rhoten, 2009; Siedlok and Hibbert, 2014), and this feature has been already acknowledged several times in the present work.

Center	Mission fragment
Future Urban Legacy Lab	… to design socio-technic innovation scenarios for relevant **global** urban **challenges**.
RESTORE COST Action	… leading to **solutions** that celebrate the richness of design creativity…
Sustainability Science Lab at Melbourne	We are working to address the **real-world problems** posed by global change…
Architecture & Climate Lab	Its mission is to propose and validate solutions […] to respond to the global crises and **challenges** of today and tomorrow.
INTERPID COST action	… achieve more efficient and effective interdisciplinary research […] to meet contemporary **global** (urban) **challenges** characterized by increasing complexity and uncertainty.
LAET (laboratoire aménagement économie des transports)	… and provide decision-support to stakeholders seeking solutions to current **critical issues** facing society.
Urban Resilience Research Network	... to identify **challenging** and necessary research **questions** addressing the gaps between theory and practices.

Table 8 – "Problem solving" arguments in missions

This is again one of the motivations of Klein and Newell analyzed in the previous section. They stated it as "Social, economic and technological problem solving". Also, in 1963, popper declared "*We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline*" (Popper, 1963).

More recently, (Lyall, 2019) identified "problem focused" as one of the two types of interdisciplinarity, whereas the other is "academically oriented".

So the problem-oriented feature of inter/transdisciplinary research has been broadly addressed in the literature, and the results provided in this section corroborate what was found in the literature: there is a big influence of "problem oriented" approaches in the work of contemporary inter/transdisciplinary research centers.

The most common motivations and missions of inter/transdisciplinary research centers have been depicting. Now, the focus is turned to the barriers they found when performing their research activities.

Barriers

This chapter is crucial to the objective of this thesis. There are considerable efforts to foster inter/transdisciplinary research, but the rigid structure of the academic environment, the bureaucracy, communication issues and other barriers hinder the its opportunities to flourish.

The standardization of policies and evaluation methods that this thesis pursue is understood as a step forward in minimizing the barriers that harm inter/transdisciplinary development. Identifying and understanding the issues that hinder research integration offers opportunities to overcome the barriers (Morse *et al.*, 2007).

The majority of the bibliography consulted for the present work recognize some kind of barrier, as well as each researcher interviewed. For example in a survey performed by the National Academy of Science to academics, 71% of the respondents of an individual survey and 90% of the respondents to a provost survey declared that a major impediment for ITDR exist in their institutions (Sciences, Engineering and Medicine, 2005). In this section, literature is quoted to contrast what has been said in the literature of the barriers, and what the barriers researchers actually declared to face. Understand which are the more significant barriers both in the literature and in the practice will contribute to the determination of adequate policy recommendations.

Problems encountered when conducting interdisciplinary research include language/terminology and communication issues within the team (Milligan *et al.*, 1999; Hall and Weaver, 2001; Bruce *et al.*, 2004; Sciences, Engineering and Medicine, 2005; Morse *et al.*, 2007; Winowiecki *et al.*, 2011; Holbrook, 2013); rigidity of institutional structures and bureaucracy (Klein and Newell, 1997; Golde and Gallagher, 1999; Carayol and Nguyen Thi, 2005; Boer and Hedges, 2006; Sá, 2008; Buanes and Jentoft, 2009;

Van Rijnsoever and Hessels, 2011); problems in mutual attitudes across disciplines, lack of willingness to give up some own-discipline methods to share and learn with others', frictions caused by diversity of backgrounds (Bruce *et al.*, 2004; Gooch, 2005; Morse *et al.*, 2007; Rhoten and Pfirman, 2007); problems in meeting time requirements (Bruce *et al.*, 2004; Carayol and Nguyen Thi, 2005; Morse *et al.*, 2007; Armstrong and Jackson-Smith, 2013); and issues in raise appropriate funding (Schummer, 2004; Sá, 2008; Rons, 2011; Langfeldt and Scordato, 2016; Fam *et al.*, 2020). Those barriers that have been widely acknowledged in the literature coincide with the principal barriers expressed by the researchers interviewed.

Based on the literature review, the five major categories presented have been selected to classify the diversity of issues expressed by the researchers. These are presented in the Figure 2. Every researcher expressed at least one of the following barriers. The percentages over the total sample of interviews is presented in Figure 3. Authors that studied each barrier will be presented as we move forward with the analysis. The combination of gathered data of the centers and the literature consulted give fundamental understanding in order to select and provide adequate policies to overcome these barriers.

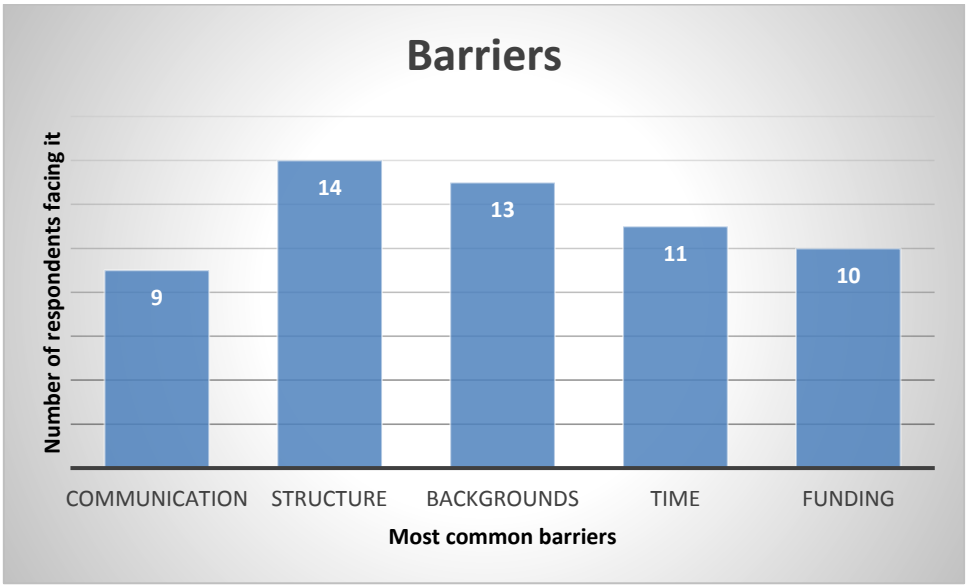

Figure 2 – Barriers of ITD

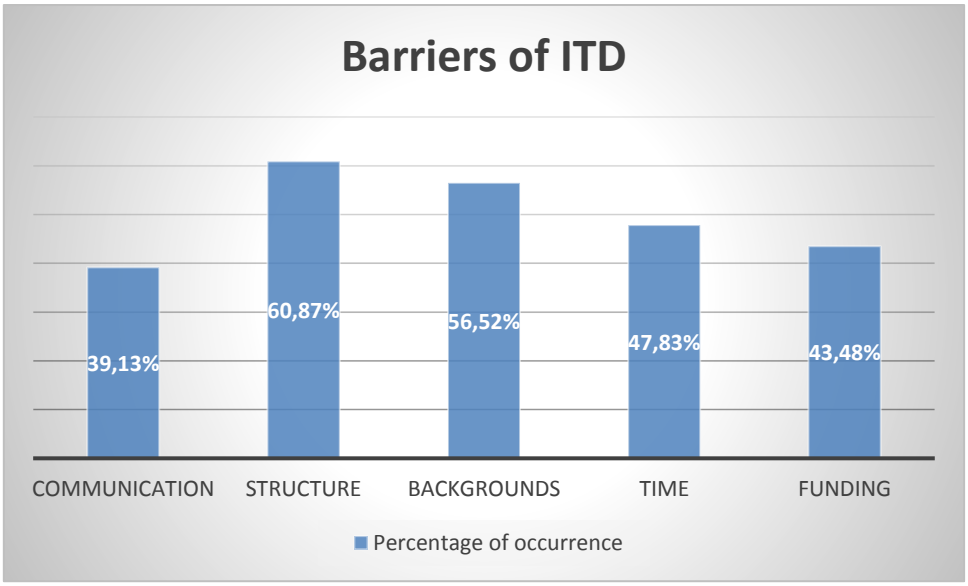

Figure 3 – Barriers of ITD - Percentages

Communication

The first category comprehends the problems related with communication and language issues. It is one of the main barriers mentioned both in literature and also in the interviews. This relation is a logic consequence if you consider that you are bringing together people from different fields, with wholly different academic backgrounds, sometimes from different countries and usually in different stages of the academic career, so it is logic that communication issues arise.

One of the academic authors that acknowledged this issue was Ann Bruce, who characterized it as "language, terminology and communication issues". Many of the respondents of her survey stressed this problem, caused by a range of factors. For instance, the same word may have different meanings in different disciplines resulting in a great deal of frustration. Communication issues were found in all types of interdisciplinary collaboration comprehended by her study: within the natural sciences, between natural and social sciences, and between qualitative and quantitative sciences. Further, later on her paper Bruce stated "good communication and listening skills" as one of the ideal qualities of an interdisciplinary researcher (Bruce *et al.*, 2004).

The results of the quantitative analysis of the semi-structured interviews showed that 9 out of 23 (39.1%) of the researchers mentioned that in their centers they have or had problems related with communication. The challenge of building a common language was avowed by many of the respondents.

It is imperative for management of laboratories to put into practice strategies that foster building a common language and leave aside distant and simplistic exchanges with researchers of other fields. The decisions made by the management of the fundamental to determine the form that interactions should take (Sciences, Engineering and Medicine, 2005). Further advices on how to overcome this barrier is given in the section "Policy recommendations".

Structure

Another common issue slightly mentioned in previous sections is related to the tradition in and the structure of academic institutions, where research and teaching activities are organized in discipline-based **departments**. This barrier was also investigated many times in the literature and from different perspectives (Golde and Gallagher, 1999; Sciences, Engineering and Medicine, 2005; Boer and Hedges, 2006; Levitt and Thelwall, 2008; Sá, 2008).

The disciplinary structure of science is an artifact of nineteenth and twentieth century social and political organization (Wagner *et al.*, 2011), and nowadays it is widely accepted the idea that this structural disciplinary organization hampers potentially valuable and innovative interdisciplinary interactions (Rons, 2011).

The structural barrier most commonly found in the literature is the one related with the reward systems. Most universities' reward system and hiring policies to researchers are based on criteria biased in favor of disciplinary, considering outputs such as publications. It is generally assumed that interdisciplinary research collaborations are less rewarding than disciplinary collaborations in terms of publications, recognition and career advancement (Boer and Hedges, 2006; Levitt and Thelwall, 2008).

Further, it was found that in a researcher's academic rank in terms of the path to a full professorship, interdisciplinary research collaboration is unrelated with academic rank (Van Rijnsoever and Hessels, 2011).

In a nutshell, outstanding literature state that existing reward structures (disciplinary oriented) are often mentioned as the main barrier for inter/transdisciplinary research (Boer and Hedges, 2006).

In accordance with what was found in the literature review, germane problems are the most mentioned by interview respondents. A total of 14 out of 23 (60.9%) mentioned to have faced issues related with the structure of academic institutions, how departments are structured, its bureaucracy, etcetera.

> *"In the context of increasing support for interdisciplinary modes of research, many in the policy, scientific, and academic communities propose that universities should change structurally to reduce the barriers to investigation that involves researchers from multiple disciplines".*
>
> *(Sá, 2008)*

Backgrounds

The following barrier chosen among the most frequently mentioned by researchers is associated with the frictions and misunderstandings that arise by mixing in the same place (physical or not) people with different backgrounds, different formation, diverse method and approaches, and fundamentally different manners of doing research. In this case, 13 out of 23 respondents recognize having faced problems of this nature, representing the 56.5% of the sample.

It is typical for those taking part in an interdisciplinary research project to still be firmly rooted in their own disciplinary traditions, which can dominate their values and behaviors (Siedlok and Hibbert, 2014). The present point is closely correlated with the one of communication and the need of a common language, but in this case is wider because background

problems comprehend different methodologies, opposing ideas and epistemologies, academic egos, antagonistic disciplinary cultures.

Further, the scientific characteristics of a discipline are not the only distinctive aspects. There are various symbolic resources, habits, and other cultural accretions that are more-or-less essential, but are all associated with how communities conduct their business (Siedlok and Hibbert, 2014).

The National Academy of Sciences (2005) asserted that, as interdisciplinary research is typically collaborative and involves people from disparate backgrounds, it may take extra time and difficulties for building consensus and for learning new methods, languages and cultures. Morse *et al.*, (2007) also acknowledged the diversity of backgrounds as a barrier but he introduced a concept that will be developed later, which is that some barriers can also inter/transdisciplinary research, depending on the context.

Respondents of the interview manifested repeatedly the struggle they do for understanding the other's point of approaching a problem. A laboratory willing to develop an interdisciplinary methodology will have to build a common understanding in terms of vocabulary, methods, approaches, processes, and interactions. A significant part of the respondents mentioned that scientists, usually those coming from hard-science backgrounds such as engineering or mathematics tend to disregard the contributions or others coming from arts, humanities, social sciences, and the qualitative analyses in general.

When trying to overcome this barrier, respondents highlighted the importance of being aware of the personal and interpersonal skills when making the recruitment of the center. It is, they said, inevitably that disagreements happen because diverse disciplines have diverse points of view, sometimes contradictory, but the way differences are approached and the mutual respect is determinant to the success of the center. Rhoten and Pfirman (2007) are two authors who have studied

interpersonal factors in their research. Further development on this theme is done on the “gender” section.

Time

The next barrier is related with the issues that arise with the larger time that entails perform inter/disciplinary research in comparison with disciplinary research. It takes more time because, as explained, researches involving in this type of research need to build consensus on methods, approaches, terminology and other aspects before event start addressing the topic that brought them together.

One of the authors taken as reference for the choice of this topic was Wayde Cameron Morse. He identified “extended time requirements” as one of the barriers to expanding beyond traditional research structures (Morse *et al.*, 2007). In this line, Rhoten and Pfirman (2007) found that the creation of an article that integrates a diverse range of disciplines usually requires more time than a monodisciplinary publication.

In this case, 11 out of the 23 respondents alluded to have faced issues associated with meeting times requirements or deal with the longer times that involve working on an inter/transdisciplinary basis, representing a 47.8% of the sample.

Funding

The last barrier of our analysis is closely related with the consequences of biases in the structure of universities. A total of 10 respondents declared to have faced difficulties to find proper funding, representing a 43.5% of the sample.

Interdisciplinary research is usually regarded as harder to evaluate in terms of funding proposals (Sá, 2008). To tackle this issue, funding instruments and review criteria are key elements in how a research funding agency evaluate interdisciplinary projects.

To understand the beginnings of the funding issues that inter/transdisciplinary centers are facing today, a brief historical track has to be done.

The calls for interdisciplinary approaches was born jointly with a demand for the universities to restructure their academic offers. There is an historical claim that the disciplinary mode of research production leads to an excessive fragmentation of knowledge (Klein, 1990; Sciences, Engineering and Medicine, 2005). The continuing specialization of fields is reflected on the organizational structure of universities. The phenomenon of subdivision of disciplines is often criticized as leading to the formation of departmental 'silos' whose researchers do not communicate across disciplinary and organizational boundaries (Sá, 2008). This, simultaneously, produces several disincentives for interdisciplinary research.

In order to circumvent the difficulties that implies a restructuration, as well as other difficulties in secure funding, publish and recognition faced by those faculties who pursuit interdisciplinarity, universities have traditionally created interdisciplinary research centers and institutes, also called Organized Research Units (ORUs). Organized research units display huge variability in goals, purposes, functions, organizational structures, and underlying activities (Sá, 2008).

Those centers have enormously helped the early development and funding for interdisciplinary research, and it was increasingly common to see collaborations more and more close with industry. Bozeman and Boardman (2003) assert that federal funding agencies in the United States have helped institutionalize the ''multi-discipline, multi-purpose,'' center, whose purposes include collaborating with industry, resource and equipment sharing, and technology transfer. "Despite inherent competition between centers and academic units, administrators have found ways to emphasize common objectives in education and research" (Bozeman and Boardman, 2003).

Now coming to a more contemporary view, ways to prompt inter/transdisciplinary research collaborations are an increasing point of attention for science policy. There is concern that 'regular' funding programs, involving advice from disciplinary experts and discipline-bound

viewpoints, may not adequately stimulate, select or evaluate this kind of research (Rons, 2011).

One tangible example that there are an outstanding concern about promoting inter/transdisciplinary research is that the European Science Foundation include it in their European Peer Review Guide as one of the seven typical categories of funding instruments: “Collaborative Research Projects (funding for joint actions by research groups and if appropriate private actors, often interdisciplinary projects)”.

More, the European Research Council’s president, Prof. Jean-Pierre Bourguignon gave a speech in September 2019 about the importance of supporting interdisciplinary research, named “Supporting Interdisciplinarity, a Challenging Obligation”. In his lecture, Prof. Bourguignon express the importance of being conscious of the considerable variety of situations that involve interdisciplinarity, the relevance of supporting risk-taking projects, and the key role of appropriate evaluation in interdisciplinary projects.

In spite of the specific policies aimed to spur interdisciplinary research in Europe that have been launched, funding is still one of the most significant barriers researchers performing ITD research have to face, and further policy design and implementation is required to overcome this drawback.

Nonetheless, some authors agree that even though many programs and policies were put in place, the problem is that each funding agency has its particular set of funding instruments and there is not a generally accepted method to adequately select and evaluate interdisciplinary research (Rons, 2011; Langfeldt and Scordato, 2016). Here we found other call that lines up with the main aim of this thesis: set standardized procedures that favor inter/transdisciplinary work.

Finalizing our analysis of barriers that harm the potential of inter/transdisciplinary research and education, some clarifications have to be done in order to properly understand how to weigh the impact of the barriers and eventual modifications on policy or structure.

It is wrong to generalize that institutions that have barriers for interdisciplinary research are in some grade poorer in quality against those ones that face less barriers. As opposed, it is ironic that some of the barriers are consequences of otherwise excellent academic system that support frontier research at every level and achieves great depth in training future generations of scientists (Sciences, Engineering and Medicine, 2005).

> *"The overall effect of barriers is hard to quantify, but even slight deterrents to researchers who are trying to reach career milestones—such as earning a degree, locating an academic position, raising funds, attaining tenure, publishing the results of research, or sustaining a long-term research portfolio—can become substantial and even onerous in the aggregate."*
>
> *(Sciences, Engineering and Medicine, 2005)*

Evaluation

Before introducing the policy recommendations collected from the literature and selected looking into how research centers are currently performing, a depiction of what has been said about the evaluation of interdisciplinarity and transdisciplinarity in the literature will provide important understandings and set the baselines to later propose policy recommendations.

Criteria for assessment are the least understood aspect of interdisciplinary studies, partly because they have been least studied and partly because multiple motivations and tasks militate against any single standard (Klein and Newell, 1997). No objective methods have been established for readily evaluating academicians' productivity or the levels of integration between the disparate fields of interdisciplinary research projects (Anzai *et al.*, 2012).

What Klein and Newell said more than 20 years ago is what today researchers still assert. One of the main barriers that interdisciplinary and

transdisciplinary research and education have to overcome is that the evaluation policies applied today are failing to catch the implied complexity of ITDR and the diversity of their outcomes, and thus harming its development.

There are many authors that argue that interdisciplinary research projects and their publications are difficult to evaluate (Rhoten and Pfirman, 2007; Klein, 2008) because the system of referees and experts is organized in a disciplinary manner (Metzger and Zare, 1999). Because of that, in this section a framework developed by (Klein, 2008) that synthetize the outstanding studies on evaluation criteria for research is presented as a first approach to proper evaluation of interdisciplinary projects (see table 9). He provided seven generic principles collected from the emergent literature in his quest for the best procedure for research evaluation.

The principles provided by Klein provide a valuable starting point for the setting of standardized procedures for inter/transdisciplinary assessment, as well as the quest for adequate success/failure indicators.

> "Appropriate evaluation is made, not given. It evolves through a dialogue of conventional and expanded indicators of quality. Traditional methodology and statistics have a role to play, but they are not sufficient".
>
> *(Klein, 2008)*

Evaluation is very important to improve the standard of inter/transdisciplinary research. When evaluating this complex and risky type of research, the progress is investigated by comparing the performance with the objectives of the research (Krott, 2002).

Krott enlarges, that evaluation may produce the information needed by researcher, stakeholders, and the whole society to assess the strengths and weaknesses and improve specific research projects.

Principle	Detail
#1 Variability of Goals	ID and TD research are not driven by a single goal. Some chose ITD for the production of new and broad knowledge of a particular phenomenon, others mentioned the development of technical equipment or products. Variability of goals in turn drives variability of criteria and indicators of quality.
#2 Variability of Criteria and Indicators	There are also different approaches to the assessment of ID quality. Conventional metrics has been privileged traditionally: number of patents, publications, prestige rankings. Others support the principle of variability and judge projects under outcomes in and feedback to multiple fields; expanded expertise, vocabulary, and tool sets, etc.
#3 Leveraging of Integration	Studies of ID and TD research call attention not only to outcomes but also to the quality of the process. Integration is widely considered the crux of interdisciplinarity, and (Krott, 2002) deems integration the critical point for evaluation in transdisciplinary projects.
#4 Interaction of Social and Cognitive Factors in Collaboration	Systematic communication of research partners and subprojects lessens shortfalls of integration. The clarification and negotiation of differences lessen misunderstanding and strengthen the conditions for consensual modes of work. Intellectual integration is leveraged socially through mutual learning and joint activities that foster common conceptions of a project or program and common assessments.
#5 Management and Coaching	Competence is defined partly in terms of how well the management of projects and programs implements consensus building and integration. Therefore, evaluation must consider how well the organizational structure fosters communication, including networking among subprojects.
#6 Iteration and Transparency in a Comprehensive System	Studies of interdisciplinary and transdisciplinary collaboration highlight the overriding importance of iteration to ensure collaborative input, transparency, and common stakeholding. The key dynamics are feedback to the mission of a program and transparency of criteria. **Feedback allows for context-related adaptations** that improve the research process and conceptual framework. **Transparency requires that both evaluators and participants are informed of criteria** from the outset and, ideally, are involved in defining them.
#7 Effectiveness and impact	Principle #7 returns full circle to Principles #1 and #2: variability of goals drives variability of criteria and indicators. One of the criteria of quality cited was effectiveness in advancing epistemological understanding or pragmatic viability in concrete settings. Unintended consequences and unforeseeable long-term impacts, though, cannot be captured by a priori measures. “Interdisciplinary impacts,” (Mansilla, 2006) cautions, “are often diffused, delayed in time, and dispersed across diverse areas of study.

Table 9 – Seven generic principles for evaluation (based on (Klein, 2008))

The analysis of the semi-structured interviews performed with members of inter/transdisciplinary centers showed that 7 out of the 23 respondents recognized to have problems associated with the way they are evaluated.

Gender

The gender composition of the centers has been studied to determine to what extent the results obtained by Rhoten and Pfirman (2007) have been disseminated and effectively incorporated in research centers in Europe. This section provides key insights to be considered in the statement of policy recommendations, and it is combined with a probe of the concerning literature.

Despite this context of increasing enthusiasm for interdisciplinarity, little is known about which students and scientists align with interdisciplinary education and research (Rhoten and Pfirman, 2007).

Some authors in the literature have put the focus on the participation of women in interdisciplinary research (Rhoten and Pfirman, 2007; Van Rijnsoever and Hessels, 2011), whereas others looks at the role of female scientists in academy (Haier *et al.*, 2005; Fehr, 2006).

Before immerse ourselves in the relationships that literature provides among women and interdisciplinary work, we consider opportune to state a limitation advised by Rhoten and Pfirman (2007): "*over-generalizing and over-essentializing differences between women and men is a common pitfall, and one we do not wish to stumble into here by arguing for generic categories*". Also, they point out that findings made for gender differences may apply in some cases to other minority groups.

The first thing that needs to be pointed out is that there is solid evidence of studies in cognitive psychology and neuroscience that proves that women and men have different learning styles, career behaviors and work preferences (Rhoten and Pfirman, 2007). For instance, whereas men tend to look for abstract and theoretical arguments, dissociating it from any distracting information, women are more apt to see and make

connections between ideas and the larger context (Kimura, 1999; Halpern, 2000).

This complements the outputs of the investigation done by Van Rijnsoever and Hessels (2011). They found, after administering a survey to 303 scientific employees (209 males and 94 females) working at Utrecht University, Netherlands, in June 2006, that female researchers engage more in interdisciplinary research collaboration than male researchers (among other findings not relevant for this work).

Further studies on psychology of gender literature have argued that females are more likely to be inclined toward group work and that males are more apt to prefer independent work (Hayes, 2001).

Supplementary, Pinker (2005) found that there is an average difference between men and women of about one standard deviation in the preferences of work: whereas within women prevails the desire to work with "people", among men abound the desire of working with "things". Consequentially, Rhoten and Pfirman (2007) analyses, "*the occupations that fit best with the 'people' end of the continuum could be considered 'problem-oriented' in their focus (e.g., medical practitioner, social worker, lawyer), whereas the occupations that fit best with the 'things' end are more concerned with fundamental theory, experimentation and/or computation (e.g., physicist, chemist, mathematician).*" This finding already provides preliminary results of the inclination of women for working in inter/transdisciplinarity, which is most of the times problem oriented.

In addition, research suggest (Max, 1982; Rolin, 2004) that female scientists may not be (or want to be) as committed to the traditional social rules of science and style of interaction. Thus, this findings provides another possible reason why women may feel more attracted to participate in unexplored interdisciplinary fields, particularly at early stages of field development (Rhoten and Pfirman, 2007).

As shown, there are more than just cognitive differences between female scientists and male scientists. The modern scientific method and most

modern disciplines are based on masculine epistemology and knowledge which emphasize the principles of objective rationality, reductive explanation, and dichotomous partitioning between the social and natural worlds (Fehr, 2006; Rhoten and Pfirman, 2007).

Complementing these studies, there is a common explanation to the results presented above of Hayes et al. which argues that while women may be more inclined toward scientific collaboration, they are also likely to be more marginalized within the culture and structure of traditional science (Rhoten and Pfirman, 2007). As a result, and perhaps despite work-style preferences, women tend to be more limited in their access to formal and, particularly, informal networks, resources, and opportunities that often foster team-collaboration (Fox, 2001; Corley and Gaughan, 2005).

Now, the results of the gender studies of the sample of 23 inter/transdisciplinary research centers will be presented. The aim of this analysis is to determine if the results found by Rhoten and Pfirman (2007) has been successfully incorporated, and then a larger number of female researchers have been incorporated to the centers; or the biases of science and most scientific disciplines toward masculine epistemology are still present, allowing center to improve their performance by hiring female personnel.

Out of the 23 centers that compose the sample, 19 provide sufficient information about the composition of the stuff, and then the gender composition of those 19 centers will be depicted.

By looking at the Figure 4, it seems that there are not significant differences about the presence of male and female researchers in the research centers of the sample. In Figure 5, the data is presented in an alternative way to provide a different point of view.

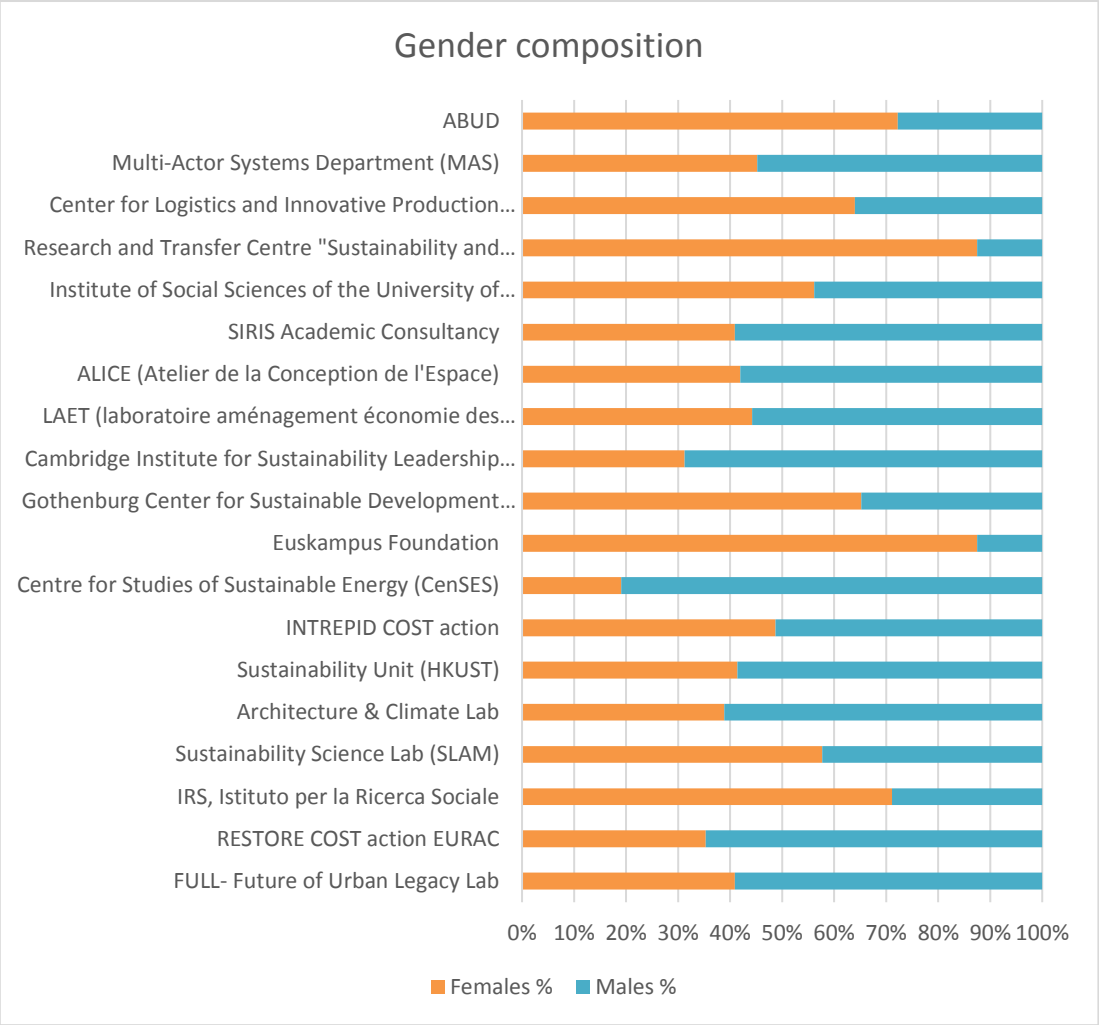

Figure 4 – Gender composition of the centers

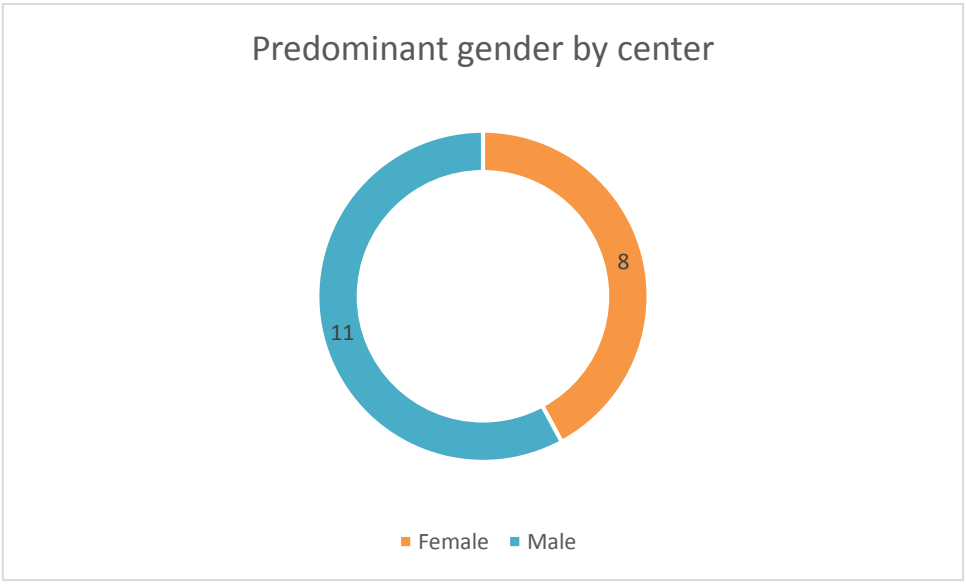

Figure 5 – Predominant gender of the centers

As can be seen in the Figure 5, there are 11 centers in which the presence of men is larger than the presence of women, whereas for the remaining 9 centers that provides this data on their websites, women are found in more quantity than men.

Those results might indicate that centers are unsuccessfully attracting more women into inter/transdisciplinary work, feature that Rhoten and Pfirman (2007) recommend as women are more likely to perform effective and efficient ITD research.

Nonetheless, the results are not conclusive, and further research is required to determine what is the optimal gender composition of the centers, and how the presence of more women affects the outcomes of the research.

Other aspects of the composition, as the proportion of professors, students, researcher fellows and more was first proposed to perform an analysis. Unfortunately, the data provided in the websites was not sufficient to perform this analysis, and further field research is needed (and advised) to study academic stage the composition of the centers and how it affects their performance.

Policy recommendations

Based on the extensive literature review and the analyses performed to the sample of 23 interdisciplinary and transdisciplinary research centers focused on urban sustainability, mostly located in Europe, this section provides 7 policy recommendations in order to assess the performance of centers willing to engage in more effective and efficient forms of inter/transdisciplinarity.

1. Team teaching

In this section we will highlight the benefits that literature (Klein and Newell, 1997; Sandholtz, 2000; Sciences, Engineering and Medicine, 2005; Fam *et al.*, 2020) suggest team-teaching has towards interdisciplinarity education. It has been argued that traditional disciplinary education is

insufficient to develop the skills and competences that are needed to perform successful interdisciplinary research.

When the lectures are taught by individuals, the assumptions and the individual perspectives of the professor are transmitted to the students, usually leaving differences in underlying assumptions unexplored and the integration of the concepts remain up to students (Klein and Newell, 1997).

"*Students are prepared for the complexities of IDR when they are encouraged to understand and pursue multiple disciplines and to address complex problems from the perspective of multiple fields in their undergraduate and graduate studies"* (Sciences, Engineering and Medicine, 2005).

In interdisciplinary courses, whether taught by teams or individuals, faculty is involved in the design of the course. Individuals contribute their own expertise, but they grow intellectually through exposure to other viewpoints and the interrogative learning that ensues (Klein and Newell, 1997). Both students and faculty benefit from encouraging team teaching of interdisciplinary courses. Moreover, interdisciplinary team teaching strengthen the professional growth of not only students teachers but also the veteran teacher who collaborate with them (Sandholtz, 2000).

For students, the exposure to teachers coming from different disciplines may lead to broader understanding, whereas for the faculty the ability to collaborate with researchers in different disciplines may lead to new understandings of their own and an ability to provide better an broader explanations to students (Sciences, Engineering and Medicine, 2005).

Further, results of Sandholtz (2000) show that interdisciplinary team teaching is an effective way of achieving an increase in collaboration, encouraging experimentation with new teaching strategies, enabling observation of colleagues in a natural setting, and fostering collegial analysis of instruction.

Despite the major advantages of team-teaching, it is sometimes difficult to implement as it represents an increased economic effort, because it involves paying multiple lecturers where before there was only one. An alternative is to design courses in such way that there is a team envelopment, but the whole team of lecturers are not giving classes during the whole course. A team may teach together for the initial offering of a course; then as individuals become more comfortable with the perspective and contributions of other disciplines, they may teach sessions individually (Klein and Newell, 1997). This mode of team planned individually taught teaching is more often found on universities.

Institutions that encourage team teaching may favor both interdisciplinary research and teaching through better method to recognize and reward teachers who are teaching outside their departments (Sciences, Engineering and Medicine, 2005). Nonetheless, the dominant structures on universities give priority to teacher's autonomy more than collaboration (Sandholtz, 2000). Further policies to encourage these practices include reward for lecturers that contributes with interdisciplinary team-taught courses through advantages in hiring and tenure procedures. There is a need for systematic change within both university administration and funding institutions to facilitate and reward collaborative work, such as teaching collaboration (Fam *et al.*, 2020).

2. Use proper interdisciplinary indicators in evaluation

Evaluating research centers by the number of publications or evaluating the quality of publications with bibliometric indicators such as the number of citations is widely used in the research environment. Indeed, citation analysis in several forms is widely accepted as a basis upon which to develop measures of interdisciplinary research (Wagner *et al.*, 2011). Notwithstanding, there is no agreement on the literature about the extent to which interdisciplinary publications have more impact in term of citation. Levitt and Thelwall (2008) found results that suggest the assumption of a paper will have more impact for its interdisciplinary character is wrong. Thus, other measures must be encouraged in order to avoid biases against ITDR.

> "*The results suggest that research in multidisciplinary journals is not more highly cited than research in monodisciplinary journals. A clear policy implication of the findings is that the promotion of Mode 2 [transdisciplinary] research is unlikely to be reflected in improved citation scores. Moreover, if Mode 2 research continues to be accepted as valuable, despite its apparently lower citation level, then all interdisciplinary researchers should not be penalized for lower citation levels than other researchers*"
>
> *(Levitt and Thelwall, 2008).*

Since there is still not an agreement on the opportunities that inter/transdisciplinarity papers have to obtain more visibility and attain more impact, the findings of Levitt and Thelwall should be sufficient to avoid the evaluation based on citation scores. If centers measure the effectiveness of their researchers and their publications with base on the impact indicators, they may fail to catch the spirit of inter/transdisciplinary collaborations.

The National Academy of Science provide "special evaluation measures of IDR programs" as one of their institutional recommendations to best facilitate IDR, without digging so much in which are those measures. More, Van Rijnsoever and Hessels (2011) assert that interdisciplinarity should be valued in performance evaluations and in the appointments of academic staff, otherwise procedures based on bibliometric quality indicators overvalue disciplinary success and undervalue interdisciplinary research efforts. Further development on procedures that support adequate evaluation has been done in the "Evaluation" section.

Currently, leaving aside bibliometric indicators, the evaluation of interdisciplinary projects relies merely on conventional qualitative methods such as peer review (Anzai *et al.*, 2012). Worryingly, Langfeldt and Scordato (2016) suggest that peer review is prone to different kinds of generic biases and it may disfavor interdisciplinary and other kinds of non-conventional research.

In addition, even if there is still no outstanding agreement, literature do suggest some diverse indicators that can be employed in assessment of inter/transdisciplinary research.

Carayol and Nguyen Thi (2005) proposed an indicator, or "measure of interdisciplinarity", based on the diversity of research production across scientific domains. Similarly, Porter and Rafols (2009) developed an "integration index" to measure to with extent an interdisciplinary paper integrates diverse field.

Further, an interesting insight of how to assess the performant of a projects that may be applicable to inter/transdisciplinary projects is presented by Knight and Pettigrew, and shown below:

Processes of the project	Indicators of project performance
Leading and organizing	Changes to membership of the collaborative Delivery in relation to initial timescales and budget Delivery in relation to stated objectives Learning about managing research projects
Collaborating	Change in social capital Whether collaborators work together again and/or do further collaboration projects with others Enduring relations between collaborators Learning about collaboration
Researching	Knowledge contribution (about the subject of inquiry) Methodological innovations Publications, events Learning about the subject of inquiry by participants, and by outsiders
Valuating	Score for formal evaluation (absolute, ranking) Perceptions of failure or success Esteem and impact (academic and on practice) Job promotion for participants, or other forms of career benefit Citations of publications New funding and or new collaborations for participants

Table 10 – Indicators for project performance, from Knight and Pettigrew (2007)

To close this recommendation, a caveat in the quest for determining which are the most appropriate indicators to measure and/or assess interdisciplinary projects is done by the team of SHAPE: "*Ideas of failure and success can differ when considered from the perspectives of different disciplines, and their different groupings within each project. This means that we cannot establish one unique list of factors that determine the success or failure of an inter- or transdisciplinary project.*" (Baptista *et al.*, 2019)

3. Tenure and hiring for ITD researchers

Those pursuing academic milestones should not see engaging interdisciplinary work as a deterrent for their objectives. Instead, if engaging this kind of collaborations help them to achieve career objectives, then more and more people will engage in ITDR. Many authors in the literature has suggested implement measures that reward ITD collaborations with tenure and hiring benefits (Sciences, Engineering and Medicine, 2005; Boer and Hedges, 2006; Rhoten and Pfirman, 2007; Van Rijnsoever and Hessels, 2011).

One of the factors that literature recognize that hinders inter/transdisciplinarity is that deans, department chairs and other administrators are rewarded for strengthening their own departments and not for building links to others (Sciences, Engineering and Medicine, 2005). This issue was also recognized by some of the respondents of the semi-structured interview performed by the team of TrUST. Such claims were included in the category of "structural barriers". Existing reward structures usually biased toward disciplinary outputs are often mentioned as the main barrier for inter/transdisciplinary research (Boer and Hedges, 2006; Van Rijnsoever and Hessels, 2011).

Institutions should seek for reward policies that incentive leaders to create inter/transdisciplinary programs. Further incentives may include encourage departments to share indirect cost revenues (Sciences, Engineering and Medicine, 2005) to foster collaborations among different departments.

The National Academy of Science include undertake changes in the reward structure as one of the most important reforms that institutions should apply: "*Faculty who conduct IDR need professional recognition comparable with that given to faculty who conduct single-discipline research*" (Sciences, Engineering and Medicine, 2005).

This policy recommendation runs in parallel with the funding policies (see recommendation number 5). It is not enough to update funding policies if still interdisciplinary researchers will be equally harmed in other aspect.

> "*If funding agencies, university leaders, and individual scholars plan to increase their investment in interdisciplinarity, such initiatives should be accompanied by strategies that facilitate the preferences and mitigate the consequences of scientists who choose this path while on the tenure track*".
>
> *(Rhoten and Pfirman, 2007)*

The present advice is pointed to those centers that are embedded in a University structure. Many university researchers complained about the lack of incentives for doing inter/transdisciplinary research, for example in terms of promotions in academic rank. A promotion in academic rank can be seen as a reward a researcher receives for his or her research success (Van Rijnsoever and Hessels, 2011). Further, Klein and Falk-Krzesinski (2017) warn that without a common agreement on policies for manage promotion and tenure for interdisciplinary, local efforts are hindered.

4. Develop formal and informal communication strategies

For those institutions willing to engage into more inter/transdisciplinary research and education forms, the initial steps must be to set strategies that foster the fluency of communication. Many of the respondents of the survey have acknowledged to have (or have had) communication issues.

Both formal and informal sides of the communication strategy are relevant to achieve deeper integration. In the formal spectrum, success with integrated research requires the development of a formal communication strategy specifying how, when, and what researchers

should communicate (Morse *et al.*, 2007). In the informal sphere, the social integration is an essential basis for conceptual integration (Armstrong and Jackson-Smith, 2013). Thus, they suggest, weekly workshops and weekend retreats may help to build stronger interdisciplinary understanding and social ties among team members, and the development of a strong team identity and integration, needed to develop a holistic plan of study within complex systems.

> "*As team members became more familiar with each other's research and thinking, they brought about greater comfort with one another's epistemological approaches, research foci, and garnered familiarity among team members.*"
>
> *(Armstrong and Jackson-Smith, 2013)*

The decisions made by the management of the fundamental to determine the form that interactions should take. Good leadership can assist interdepartmental interactions, which are often hindered by organizational structures (Sciences, Engineering and Medicine, 2005).

Communication should not simply remain formal. Regular informal interaction can facilitate many of the bonds and relationships necessary for effective teamwork (Morse *et al.*, 2007). Actively communication is specially advised at the boundaries of disciplines, where researchers usually differs on methods and grounds. Regular team meetings and presentations are expressly advised.

5. Provide seed money

One of the main barriers that respondents of the interview expressed was issues when looking for financing to their centers. Literature suggest that one feasible way to overcome this barrier is to allocate some of the funding to be used as inter/transdisciplinary seed money.

To allocate fund for seed money means to destinate a part of the budget to initiate a project, or to finance some activity that is in an early stage. Interdisciplinary and transdisciplinary research often benefits from this funding strategy, because in these kinds of research the outcomes are not easy to determine at early stages, so usually these projects do not fit in

traditional funding procedures or schemes. Without such startup assistance, it is difficult for established researchers to reorient their research, because funders may be hesitant to shift toward an unproven approach (Sciences, Engineering and Medicine, 2005).

Most major universities have stablished decentralized budgeting models where the major share of the funding flows to schools, departments, and other units, leaving relatively few resources to be used for new initiatives such as interdisciplinary projects (Sciences, Engineering and Medicine, 2005). To perform effective interdisciplinary research require thinking in new forms of funding and cut across the traditional discipline-based systems of resource allocation found in most universities and research institutes (Bruce *et al.*, 2004).

Nonetheless, Van Rijnsoever and Hessels (2011) warns: "*Various instruments can be used to stimulate interdisciplinary research, not all of which are of financial nature. The availability of funding for cross-disciplinary projects or programs seems a necessary but not sufficient condition for interdisciplinary research collaborations.*"

6. Female recruiting

Several reasons for enhancing female recruiting in inter/transdisciplinary research centers have been provided in "gender" section.

Among the most important, recruitment of women might help to increase efficiency on interdisciplinary activities because it has been proved that female scientists are more predisposed to engage interdisciplinary work (Van Rijnsoever and Hessels, 2011).

Women are more prone to prefer to engage in activities that involve work with people, feature that may be considered as related to problem oriented focus (Rhoten and Pfirman, 2007), and so it is inter/transdisciplinary research.

Attracting and keeping enough female scientists in academia is difficult (Romito and Volpato, 2005). Still, the results of Van Rijnsoever and Hessels (2011) provide an additional argument for keep the focus on it.

7. *Foster the involvement of humanities and social sciences, and extra academic agents*

The seventh policy is closely related with the aim of the investigation carried out by SHAPE project (Baptista *et al.*, 2019) that has been explained earlier. The issue to address is that arts, humanities and social sciences are very often excluded from the traditional scientific research communities, as well as industry investigators. This fact was also pointed out by some of the researchers that answered the semi-structured interview carried out by TrUST project. There is an underrepresentation of these disciplines in the majority of the scientific journals, and so it is in the directories of the inter/transdisciplinary centers.

Extending partnerships to the humanities and other sectors is required to address complicated societal problems (Sciences, Engineering and Medicine, 2005) because they provide key insights that enlarge and enrich traditional scientific viewpoints. Some of the complex and wicked problem that characterize interdisciplinary research, such as poverty, demands cooperation between scientists with diverse backgrounds both in natural and social sciences (Sillitoe, 2004).

In what regards involving industry actors in collaboration, the National Academy of Sciences (2005) asserts that academic researcher that are more interested in the applications of their research results lead to fruitful partnerships with substantial benefits for all partners, and may also carry private funding to laboratories.

Attracting staff from outside academia may increase the propensity of interdisciplinary collaborations. University managers should consider relieving the current financial barriers for industrial researchers to return to academia in order to enhance the diversity of university staff (Van Rijnsoever and Hessels, 2011).

> *"Creating adequate environments for the practice of interdisciplinary research is often viewed as a managerial problem*

that requires academic leadership. Rhoten and Pfirman (2007) claims that there is no lack of external support to or motivation from the faculty to engage in interdisciplinary research, but of systematic implementation of measures to facilitate such work." (Sá, 2008)

Conclusion and Ideas for future research

Much has been said to the benefits of interdisciplinary and transdisciplinary research: it is an approach that allows to solve wicked and complex problems, it enriches the perspectives and the knowledge of the researchers by bridging their knowledge with other disciplines, it provide holistic outputs and outcomes that are valuable for the entire society, etc.

Nonetheless, still the centers and institutions that chose to engage in this kind of research face significant barriers that obstruct the appropriate development of the collaborations.

When contrasting the theory and the analysis of practical cases, it was found that most of the barriers that inter/transdisciplinary centers are currently facing were already acknowledged by the literature more than 10 years before, but still the recommendations provided cannot avoid the occurrence of such issues.

Then, it suggests that the manifestation of the factors that hinder inter/transdisciplinarity opportunities is not new. In fact, the problems have been the same for more than 10 year. It requires a change in the implementation of policies to provide an adequate answer to this problematic. To make it explicit, in the current European environment the underlying problem is not the lack of incentive policies, but the scarcity of effective implementation.

According to the results provided, the 5 barriers that respondents of the semi-structured interview stated are communication issues, problem with the rigid structure of the science and universities, problems when working with people from different backgrounds, complications to meet time requirements, and difficulties to find appropriate funding to their projects.

Accordingly, after an extensive literature review, 7 policy recommendations were given aimed to minimize these barriers and to enhance the good practices of inter/transdisciplinarity. Those 7 advices are:

- Team teaching
- Use proper interdisciplinary indicators in evaluation
- Tenure and hiring for ITD researchers
- Develop formal and informal communication strategies
- Provide seed money
- Female recruiting
- Foster the involvement of humanities and social sciences, and extra academic agents

More, guidelines for providing proper evaluation have been presented, as well as indicators to provide proper assessment to interdisciplinary projects. Problems related with improper procedures for evaluation are found repeatedly in the literature and also in the semi-structured interview.

"*A discussion of what interdisciplinary 'success' or 'failure' might look like is not straightforward and warrants context-specific reflections*" (Fletcher & Lyall, 2019). The context dependence is a key characteristic of inter/transdisciplinary projects, and it is even more in the context of non-standardization of the policies that surround them. Thus, asseverations about good practices and success/failure indicators must be done carefully and considering social, political, economic and structural factors affecting the activity of the centers.

Further research

Further research is required, and practical examinations needs to be done, to determine what are the best indicators to catch the quality of inter/transdisciplinary projects. It would be valuable to analyze the degree of interdisciplinarity of the 23 centers of the sample with the integration index proposed in "recommendation 2".

As proposed by (Sá, 2008), an interesting topic of research for further analysis would be to perform a survey depicting the funding policies under what research centers currently work. This information is rarely found

online and studying that would be worth to contrast them with the performance and stablish relationship between the funding policies and the success of the centers. That would be a step forward in the setting of standardized procedures we are pursuing. As detailed in barriers section, funding issues is one of the most common barriers that ITDR centers face.

Another area where further research is encouraged to deepen the insights provided in this work is the one proposed by Carayol and Nguyen Thi (2005), who found a correlation among the size of the lab and the impact of interdisciplinary research. This would imply field work and visiting the physical location of the centers of the sample to study their dimensions.

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