Sustainable innovation in the digital transition and disruptive technologies age

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Topic: Breaking Down Silos in Universities: Imagining Interdisciplinary Approaches to Sustainable Development Research, Education, and Practice

Abstract

In today's global context, humanity faces enormous challenges, including economic crises, global warming, poverty, ecosystem degradation, and so on. In addition, the global economic situation and the depletion of natural resources make it more complex to implement efficient and sustainable solutions as a means of reconciling human development with the planet's ecological system. The whole situation requires a deep understanding of the complex and dynamic interaction that exists between natural, economic and human systems, which are interdependent, in order to achieve sustainability goals, and maintain a balance under which such systems can exist in harmony. A promising approach, which we will present in this paper, consists in building models capable of tackling these problems holistically and efficiently; the approach further harnesses the opportunities presented by the new era of disruptive technologies to accelerate sustainable development and reinforce the linking of international efforts and initiatives, all in a bid to achieve an effective global solution.

Given the context laid out above, and to break the silos between disciplines and sectors, we propose a new strategic conceptual model for collaborative transdisciplinary research as part of the roadmap of the Centre Interdisciplinaire de recherche en opérationnisation du développement durable (Quebec Interdisciplinary Center for Research in Operationalization of Sustainable Development) (CIRODD), underlining the need for a new ambitious mission: to contribute to accelerating the transition to a global smart sustainability.

I. Introduction

Currently, global sustainability remains the most pressing need to be addressed by mankind. It is becoming a definite and urgent priority in different governments' socioeconomic strategies and development plans (Papas 2017), (Roberts 2016). Global problems such as climate change, energy, poverty and diseases often affect and involve several highly interconnected components in a dynamic and uncertain environment; this calls for coherent approaches capable of tackling complex problems through multifaceted reflections and providing cross-disciplinary tools and models. Thus, novel and effective

approaches should be undertaken in order to break silos between sectors, academic disciplines, industry and civil society.
However, the lack of a holistic vision has led to a proliferation of predominantly simplistic solutions, designed in silos, which only delay the implementation of resilient solutions. The research questions to be tackled for a sustainable development (SD) perspective are rooted in cross-cutting disciplines and sectors, which emphasizes the relevance of a transversal approach to promote collaborative research.

The effective integration of knowledge and skills relevant to sustainability requires close research collaboration that transcends disciplinary and geographic boundaries. It must encompass different types of expertise in various sectors, including academia, industry, government and civil society, to be ready to understand and manage multidimensional and dynamic environmental, economic and social complexities.
As an essential tool for tackling such complexities, technology is bound to play an increasingly central role in enabling global sustainability and breaking the silos between different sectors (Newton 2012). Recently, we have been observing the emergence of certain initiatives at the international scale (Newton 2012), (Expert 2014), (Tjoa and Tjoa 2016), (Chen 2018), as shown in the figure below (Fig.1). These initiatives support multi-disciplinarily approaches, and evidence the potential for disruptive technologies to empower the acceleration of a global SD.

Fig 1. Samples initiatives

It must be noted that these initiatives are still at early stages of development, and are facing many challenges, such as: (i) understanding cross-sectoral limits; (ii) understanding appropriate mechanisms for efficient collaborative research; (iii) dealing with the complexity of multidisciplinary approaches; (iv) understanding appropriate organizational functional models; and (v) creating appropriate and efficient multifaceted vision strategies that balance the interests of the various actors involved. These are just some of the challenges involved, with many others yet to be overcome (Roberts 2016, Wu et al. 2018). We must therefore rethink our research strategy from the different angles encapsulated in the model proposed in this work. This will allow us to meet some of these challenges, and presents us with the chance to attempt a holistic methodology at the fundamental, practical and organizational levels.

Our paper highlights a holistic approach to sustainability innovation, (cf: Fig. 3, in section III), drawing principles from a collective reflection we undertook towards the renewal of

our research center, CIRODD, funded by the Quebec funding agency, FRQNT[1]. The center brings together researchers from different universities and institutes in the province of Quebec, working in the areas of engineering, technology, humanities, and social sciences. It proposes a novel research model, which aims to define collaborative sustainable innovation. It leverages recent technological advances and considers current eco-social transitions, along with significant national and global trends in sustainable and economic development.
The primary objective of the Center's mission is to animate transdisciplinary research. This will be achieved by setting up key mechanisms and tools, such as collective intelligence, innovation practices, co-design and co-thinking, and favouring inter-sectorial and transdisciplinary collaboration. In this context, we propose a model organized in three global spheres (cf. Fig 3.) integrating: (1) strategic axes, (2) systemic approaches and accelerators, and (3) application fields.

This paper examines our research model and gives an overview of our vision, in addition to describing each proposed research area. It emphasizes the dynamic functional organization we aim to put in place, which should ensure synergies between and within the different spheres of the model.

II. Roadmap of our vision

Sustainable development and its operationalization require a transdisciplinary approach, as suggested in the literature (Scoones 2015), (Popa, Guillermin, and Dedeurwaerdere 2015), (Steiner and Posch 2006), (Elliot 2011), (Brandt et al. 2013).
In 2008, Quebec adopted its first Sustainable Development (SD) strategy, with the primary objective being "the development of knowledge". In 2013, the CIRODD was launched in response to a growing need to mobilize the research community to implement sustainable development principles in Quebec's strategic sectors and contribute to the emergence of a green economy. CIRODD was established as a unique structure comprised of more than 90 renowned researchers in the areas of life cycle assessment, process engineering, green information and communication technologies (ICT), smart buildings, green logistics, sustainability measurement and analysis, industrial symbiosis, etc. The value of CIRODD is enhanced by being at the interface of researcher networks covering highly disciplinary fields (e.g., STARaCOM[2], CIRRELT[3]), which have shown an interest in sustainable development research. As a result, the members have had the opportunity to transfer interdisciplinary knowledge between their respective research groups.
Driven by a commitment to sustained development-centered action, CIRODD focuses on developing collaboration with different actors. With this approach comes the need to truly adopt transdisciplinarity, not just to bring innovation and SD tools to industry, but also to generate and co-create cross-disciplinary knowledge.

Most of the literature (Mauser et al. 2013), (Nicolescu 2002, 2014), emphasizes the fact that transdisciplinarity, unlike interdisciplinarity, is characterized by the active involvement of non-academic actors upstream in the research process. The prefix "trans" indicates

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[2] The Centre for Systems, Technologies and Applications for Radiofrequency and Communication

[3] Interuniversity research center on enterprises networks, logistics and transportation

"work between disciplines, across different disciplines, and beyond all disciplines" (Nicolescu 2002, 2014) (Fig. 2).

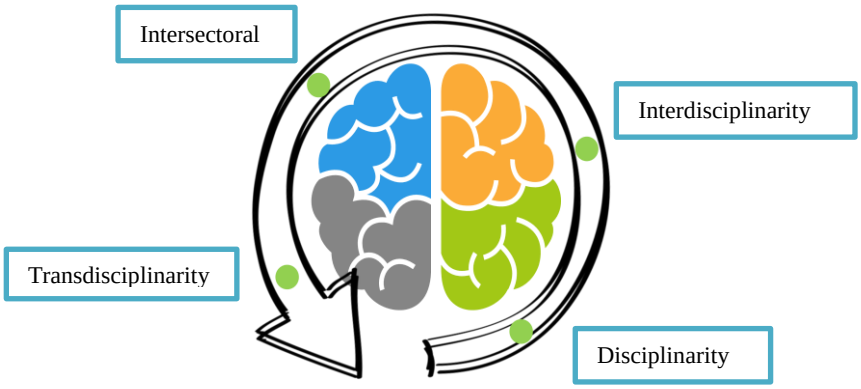

Fig 2. Transition from disciplinary to interdisciplinary

This prompts us to question the limits imposed by the disciplinary boundaries and the inclusion of all relevant actors in order to co-create a holistic approach to enable sustainable innovation, while highlighting the concept of "dynamic co-design for development" and referring to the co-creation and building of creative and collaborative capacity [16]. This led us to conceptualize a new vision with an open collaborative approach that likewise drives our proposed model, and which is described in the following section.

The global context is changing significantly, with the rapid growth of ICT and data sciences, large-scale technology adoption, the emergence of disruptive technologies, the rise of social innovation and circular economy, as well the adoption of sustainable development goals. This context offers an exceptional opportunity to develop a systemic, innovative and strategic research vision for a modern operationalization of SD for Quebec and at a global scale. In fact, this is precisely what the next research cycle programming of CIRODD (2019-2025) intends to accomplish in pursuing its primary mission of "helping to accelerate a smart global transition" empowered by ICT and digital innovation.
The state of the art and a self-assessment of the experience of the first mandate of the CIRODD underlines the need for a deeper reflection on the following three main challenges:

- How to actively involve our industrial collaborators in the SD process and move from a technology transfer approach to a co-design approach, while incorporating strategic sectors. The goal here is to generate a valuable transdisciplinary knowledge under sustainable innovation perspective.
- How to develop an effective SD operationalization strategy, based on accelerated action plans.
- How to create a dynamic and vibrant eco-system to implement effective SD innovation and bring a disruptive model capable of accelerating the transition to a smart global sustainability?

Although independent, these questions are interrelated, and bear certain similarities aspect. We note that it will be important to adopt a multifaceted approach in designing our strategy at the scientific and organizational levels, and this which will be discussed in the next section.

III. Our proposed model

In a transdisciplinary perspective of the operationalization of SD, the main objective of CIRODD's proposed scientific program is to put in place mechanisms for the acceleration of sustainable innovation. The latter can be accomplished by taking advantage of the potential of technological advances and cooperating with global initiatives in sustainable development.

a. Develop a transdisciplinary and cross-sectoral research approach integrating the most advanced expertise, tools, technologies and emerging techniques to accelerate the operationalization of SD;
b. Establish a unique sustainable innovation ecosystem that will bring together diverse actors, and that will test and validate research results in a clear and quantifiable manner;
c. Contribute to generating high-level knowledge and to training a new generation of highly qualified personnel (HQP) with principles of transdisciplinary.

Our research program is organized according to an inclusive model whose logic involves setting up mechanisms inspired by collective intelligence that will foster collaboration between the researchers involved. To effectively and efficiently realize our animation role in empowering transdisciplinary research and collaboration, we propose a dynamic functional model in a way that fosters the maximum emergence of transdisciplinary projects which cut cross different spheres, as can be seen in the figure below (Fig. 3).

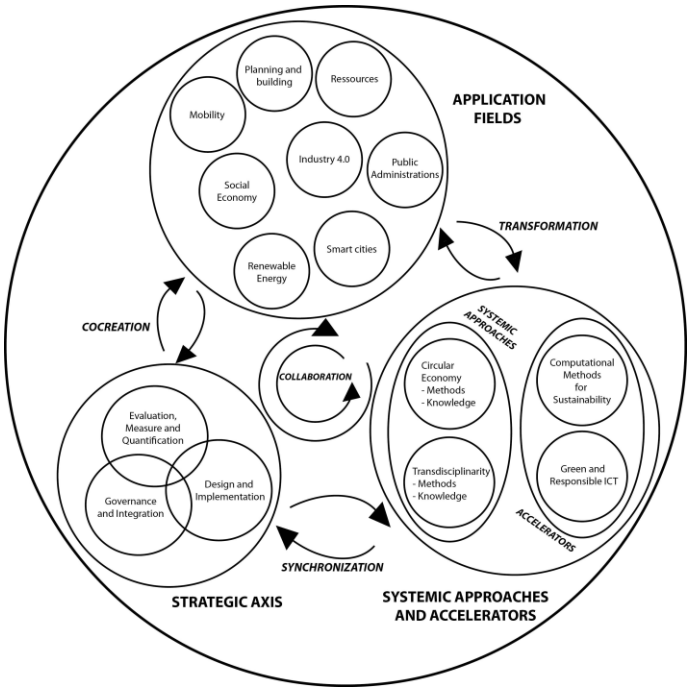

Fig 3. The CIRODD framework for operationalization of sustainable development

Since CIRODD's primary mission it is helping accelerate a smart global transition, we decided to align our research programming goals with the United Nations Sustainable Development Goals (Fig. 4).

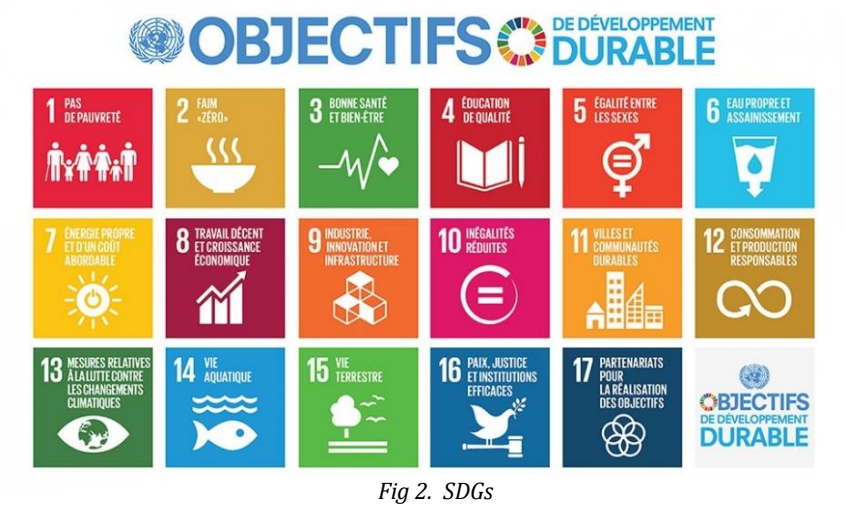

Fig 2. SDGs

The model underlying our research program is grouped into three spheres that encompass research intervention areas:

(i) The strategic axes, which constitute the axes and historical research projects at CIRODD.

(ii) The systemic approaches and accelerators: gathering non-exhaustive expertise to empower intelligent global transition.

(iii) The application fields, which are at the core of the transdisciplinary approach at the CIRODD.

The interactions between the spheres represent the driving forces and the logic of the operationalization of the SD.
Research projects that emerge from interactions between different spheres will constitute cross-thematic intersections or forums that emerge naturally in our dynamic framework. The diagram (Fig.3) forms indeed a specific but flexible framework for the different logics of operationalization of sustainable development in collaborative mode, to further extend and empower the functional organization of CIRODD 2013-2019. It targets intersectoral interaction, and sheds a light on the projections of how CIRODD will operate in a collective intelligence mode during the next programming cycle.

The interactions between the "application field" and "strategic axes" will continue to be rich areas of collaboration, since various interdisciplinary projects have already emerged and matured through these interactions. Such projects may also be able to benefit from a "combination" with or "transformation" into "systemic and accelerator approaches".

Based on the intersection between the systemic approaches sphere, the accelerators sphere, and the application fields sphere, projects will emerge which can improve, accelerate and even propel disruptive innovation in products, services, processes, business models, modes of operation, etc. The proposed model can be seen as a complex graph in which projects driving SD with high impact, lie on maximum-length paths. Ultimately, it will foster the emergence of innovative projects that will mobilize the expertise/tools/approaches of the three spheres in a transdisciplinary practical methodology.

The following part of this paper provides a more detailed description of the different axes contained in the model, as well as their distinct and common roles and objectives.

III.1 SPHERE I - STRATEGIC AXES

The strategic axes sphere consists of a combination of three fundamental and strategic research areas: (a) evaluation, measurement, and quantification, (b) conception and implementation, (c) governance and integration.
This sphere is fundamental for the strategic sustainable development of conceptual and practical methodologies. It provides the opportunity to build new tools, models, and approaches to evaluate and implement SD operationalization. This requires breakthrough reflection transcending diverse research areas and sectors. It also involves an active collaboration role with application field actors in early-stage processes as co-creators, in order to ensure a coherent strategy.
Interacting dynamically with systemic approaches and “enablers”, the strategic axes sphere could be a sustainability innovation generator. Indeed, technology as an enabler provides new innovation opportunities for these strategic axes, which can be iterative or disruptive.
Innovation is not necessarily centered on technologies, but can in fact use and lead to the creation of disruptive technologies. However, to be able to create new business models and new markets, innovation must create novel concepts and strategies. Such innovations provoke a change in concepts, bring new functioning model of the socio-economic ecosystem, and organizational as well political models, including a new value model and a different method of governance. This is why it was important to include *governance and*

integration as a main axis in the strategic axes sphere. The three axes within this sphere are:

a. Evaluation, measurement and quantification

The development of frameworks and assessment tools for quantifying and measuring sustainability, is fundamental for the development of sustainable strategies, products, and services. These allow a rigorous evaluation of existing problems and proposed solutions, in addition to identifying priorities for improvement and value creation. Hence, this axis aims to promote the consolidation, improvement and innovative development of frameworks and tools for evaluation, quantification, and measurement of environmental, social and economic impacts. It focuses on the integration of existing tools and a combination of several advances in the ICT field and data sciences, which provide interesting research perspectives. For instance, integrating monitoring tools and data science techniques can increase the accuracy of LCA results (Maurice et al. 2014).

b. Conception and implementation

In order to benefit from relevant and innovative sustainable development models and tools, it is essential that they be co-developed in synergy with the application fields and be adapted to the operational realities of decision makers.

It is also required, when relevant and appropriate, to use digital tools, analysis, and communication interfaces. This axis aims to focus on research to build bridges between theory and practice, so as to provide operational tools, which facilitate the integration of sustainability into decision making and monitoring of resulting activities. Also, it helps in the implementation of innovative methods of collaboration for more sustainable and smarter logistic networks.

c. Governance and integration

Successfully implementing SD does not depend solely on the development of operational tools and technological improvements. These tools and technical innovation must be integrated at the functional and governance levels in organizations.

Governance is the set of rules, principles and collective processes through which application field actors are involved in decision making and in the implementation of concerted actions (Betsill and Bulkeley 2006), (Rhodes 2007). This axis focuses on governance approaches and integration mechanisms that facilitate the implementation of sustainable solutions within institutions, organizations, and communities. It also focuses on better understanding the barriers to achieving these goals. This can help at many levels, e.g., in following, understanding and evaluating the implementation of SD public policies, understanding ethical and legal issues related to the deployment of SD tools, strategies and policies, and setting up initiatives with various collaborators to develop frameworks, tools and insights to manage these issues.

III.2 SPHERE II - SYSTEMIC APPROACHES AND ACCELERATORS

This sphere will play a backbone role. It helps identify the tools needed for a smart global transition, and aims to develop and deploy tools to accelerate SD operationalization. Furthermore, it also highlights the implementation of systemic approaches and key enablers for SD operationalization adapted to transition needs.

From a methodological point of view, it proposes to propel sustainable innovation, offering innovative models and tools to support innovation and sustain mechanisms. It aims to put

in place a synergistic and dynamic functional organization with the application fields and strategic spheres, considering their contextual and strategic aspects.
The sub research areas identified aim to create a connection between approaches, practices, and tools, to mobilize and optimize them into mechanisms based on an integrative approach in favour of accelerated operationalization SD.

a. Innovative methods and knowledge in the circular economy

The circular economy is already unfolding around the world, but scientific support for its systemic and holistic operationalization is necessary. This will help identify the different ways of integrating the circular economy at different scales and deploy it in different sectors.

b. Innovative methods and knowledge in transdisciplinary research

In order to achieve the transitions needed for a more sustainable world, it is essential to understand the interactions between natural and human systems in order to transform and develop them in a sustainable manner. Compared to interdisciplinarity, transdisciplinarity is characterized by the involvement of non-academic actors upstream in the research process. Effective integration of relevant knowledge and skills requires close collaboration that transcends disciplinary and sectoral boundaries. This research axis would be very valuable for defining new ways of generating such knowledge.

c. Green and responsible ICT

ICT is a fundamental enabler of economic prosperity, recently identified among the main enablers for the three pillars of sustainable development: social, economic and environmental and the principal enablers of SDGs 2030 (Sachs 2015), (Tjoa and Tjoa 2016). ICT offers a range of fundamental and methodological contributions that empower the transition by various tools and more generic models (Wu et al. 2018). A successful transition to a smart global sustainability requires a better understanding of the potential of technologies and their socio-technical impacts, as well as their cultural and ethical influence, plus the identification of additional existing or emerging enablers for sustainable development. As an example, such tools can help green and energy efficient platforms (Dandres et al. 2015), defining new sustainable business models and best practices. It must be incorporated into the calls for project and in the organizational performance indicators which can be monitored through ICT platforms. At the community level, ICT provides an optimized citizen experience by leveraging massive data, analytics and contextual management to effectively scale and integrate sustainable ICT applications for various markets (Riekstin et al. 2017). While integrating systemic approaches and the strategic spheres, this enabler empowers computational modeling and strategic decision making. It also helps to generate holistic models, integrated tools, and strategies for SDG implementation. Thus, falling under an ecosystem approach, this axis remains flexible to a dynamic and innovative adaptation to application field characters and needs.

d. Computational sustainability

Computational Sustainability is an emerging interdisciplinary research field that attempts to optimize societal, economic, and environmental resources, using fundamental methods from mathematics, data science, and computing, as well as application models and approaches in revolution 4.0 (Hilty and Aebischer 2015), (Wang and Kant 2014). It aims to develop computational models and methods to facilitate decision making, e.g., management and resources allocation, assessment tools, management approaches and system operations (transport, logistics, production, etc.), simultaneously reflecting the technical reliability and sustainability aspects.

It helps develop holistic approaches based on artificial intelligence techniques as well computational and reasoning methods, such as machine learning, constraint reasoning, game theory, stochastic optimization, etc (Chen 2018).
Computational sustainability cuts across various research areas, providing fundamental models, quantitative and qualitative decision support. Regardless of the particular tools of data categorization, visualization, and analysis used, this research area generates essential abstraction mechanisms useful for characterization, synthesis, and subsequent integration into the ecosystem's decision-making frameworks which can help in problem solving particularly for sustainability issues.

III.3 SPHERE III – APPLICATION FIELDS

Effective integration of knowledge and skills relevant to sustainability requires close collaboration between research and different economic sectors, industry, government and civil society. The transdisciplinary character and the dynamic synergy between different research area in our scientific program take on real meaning in the implementation among the application fields actors. It is in this sphere that all the added value of the CIRODD approach seems essential to actively involve different experts and actors from any existing or emerging ecosystem, at national and international level. Its role will be to bring out the ground issues that will match the expertise of the CIRODD's members, and that can lead to projects with a high potential for operationalization empowered by a collaborative and collective co-creation. The following are samples of application fields sectors we will be working with:

- Planning and building
- Mobility
- Social economy
- Industry 4.0
- Resources
- Public administrations
- Smarts cities
- Renewable energy

I.V Conclusion

This paper presented our strategic vision and the dynamic collaborative conceptual and functional model that will govern the next research program of the research Center CIRODD research center, for the upcoming programming 2019-2025 cycle. The design of such a model helps improve our ability to execute our research strategy and achieve our aim to (i) respond to the emerging issues of transitioning towards a green and sustainable economy, ii) offer models and effective tools based on an evolving and cross-sectoral approach, iii) push the boundaries of innovation to build a sustainable ecosystem that actively supports the eco-social prosperity and quality of life of our communities, and iv) generate high-level transdisciplinary knowledge on sustainable development operationalization.

CIRODD as a unique research center bringing together interdisciplinary research endeavours for sustainability has been able to develop a close and active collaboration with industry. During the last four years, CIRODD has initiated more than 35 cross-sector applicative projects and supported more than 93 researchers in various disciplines

promoting interdisciplinary collaboration. With our new proposed model, we believe we can play a more efficient role in transdisciplinary research for sustainability, increase our transdisciplinary scientific contribution and innovation for sustainability, and support and mutually reinforce complementary initiatives at the national and international levels.

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