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Implementing strong sustainability in a design process

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ABSTRACT

The emergence of a post-growth era is expected that implies rethinking the production and consumption patterns with novel design models this forces higher educational institutions to reconsider their traditional ways of teaching sustainability in their curricula. Companies also need to overcome strategies that compartmentalize environment, society and economy in their industrial strategy in order to evolve in their support for the transition. The aim of this paper is to present a design process anchored in the Strong Sustainability paradigm to overcome the gap of how Strong Sustainability could be operationalised. Design Research Methodology (DRM) has been chosen as the supporting framework for the development of this project. The Design for Strong Sustainability (DfSoSy) methodology proposed, is built on three aspects of Strong Sustainability (Milieu, Regeneration, Safe and just operating space) successively applied in a sequenced iterative design process. The latter enable the integration of thought patterns associated with integrative, systemic and fractal or multi-scale thinking respectively. Moreover, the principle of sub-optimality is highlighted as a decision principle in SoSy. Results obtain has been validated as well on the pedagogical objectives as in the usefulness of the DfSoSy. The practical contribution of this study is the DfSoSy toolkit©.

1. Introduction

In 2009, Rockström et al. (2009) proposed nine quantitative planetary boundaries (PBs) within which humanity can continue to develop safely. Crossing these boundaries increases the risk of generating large-scale environmental changes. Since then, the planetary boundaries framework has generated interest within science, policy, and practice. In a recent update, out of nine PB assessed six has been crossed (Richardson et al., 2023). Indeed, scientists have identified that the PBs related to environmental pollutants and other "novel entities" including plastics (Persson et al., 2022) and freshwater cycle (Wang-Erlandsson et al., 2022) have been exceeded. This confirms the degradation of the planet's conditions for habitability. Under these circumstances, a growing scepticism about the long-term sustainability of the dominant economic system is expressed (Vogel and Hickel 2023). For instance, the weight of all man-made artefacts is increasing, exceeding the weight of the global living biomass on Earth (Elhacham et al., 2020). The emergence of a post-growth era is expected that implies rethinking the production and consumption patterns with novel design models (Cassiers et al., 2019). Thus, higher educational institutions are forced to reconsider their traditional ways of teaching sustainability in their curricula (Persson et al., 2022). Companies also need to overcome strategies that compartmentalize environment, society and economy in their industrial strategy in order to evolve in their sustainable product development process.

Weak sustainability and strong sustainability can be seen as two different types of roles in the design of innovative systems (Chaminade, 2020). The notion of weak sustainability is related to how generate and diffuse innovations within existing systems, directing them toward technological solutions to counteract the negative impact of economic growth on social wellbeing or environmental sustainability (Johnson et al., 2017; Huesemann, 2003). In contrast, strong sustainability adopt a much broader perspective on innovation systems, including technological and non-technological innovation and, more importantly, system change (Chaminade, 2020). Addressing system changes implies acknowledging a high degree of complexity and uncertainty with regard to what to steer, how and by whom (Chaminade, 2020). It demands new forms of knowledge; system, normative and transformative knowledge (Urmetzer et a. 2018).

In two review articles, Ceschin and Gaziulusoy (2016, 2019)

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proposed a mapping of Design for Sustainability (DfS) approaches. They categorized design approaches, developed over the last decades, into five levels of innovation. The authors showed that with the increasing awareness of sustainability challenges, design models are moving from "insular" to "systemic" scope, from "technocentric" to "earth-centric". They envision that, designers should move towards the most complete and most complex level of design processes to address Strong Sustainability challenges. In that level, designers are encouraged to consider multiscale, dynamic and systemic solutions described as socio-technical-ecological systems with a focus on ongoing transitions as well as post-transition contexts. For these authors, design processes should be milieu-centred and should consider the future of existing humans, but also non-humans and future generations.

Two major limitations **from traditional sustainability assessment tools** (like life cycle assessment, carbon footprint analysis, eco-efficiency, etc.) are that, firstly, they focus narrowly on environmental issues neglecting problems that cannot be taken into account in life-cycle assessments (Ceschin and Gaziulusoy, 2016), such as interdependencies with ecosystems and non-humans actors, and when it comes to tackling social and living issues, they compartmentalize problems rather than adopting a systemic perspective. Secondly, the impact due to ever-increasing consumption proves too great compared to the associated efficiency gains; this is a technical perspective that pays only limited attention to human aspects (i.e., user behaviour during the use phase). In addition, Ecodesign tools are situated in a product innovation level, its design approaches focused on improving existing products or developing entirely new ones. At this level, new risks can emerge with a systemic effect. These include rebound effects, which prevent a reduction in the total use of material resources despite decoupling, by converting efficiency improvements into additional consumption.

Designers and future designers have been trained to perform traditional sustainability assessment related to the weak sustainability paradigm (Perpignan et al., 2018). Thus, higher education institutions and companies are looking for new skills to link "awareness" and "skills" to promote the use of "skills" in the service of SoSy. As mentioned previously, practice of designing within a strong sustainability paradigm has not yet been sufficiently implemented. In order to continue the transition to strong sustainability, we propose in this article, a methodology to adopt higher levels of innovation (socio-techno-ecological) understanding the combination and complementarity between the different levels of innovation proposed by Ceschin and Gaziulusoy (2019). The aim of this paper is to propose a design methodology to help designers integrate aspects of strong sustainability into design process. In order to overcome the gap of how Strong Sustainability could be operationalised beyond the compartmentalized approach of three dimensions (e.g. Pinto et al., 2020). This is achieved by identifying specific SoSy elements, integrating them into a design framework and then testing them with several case studies.

In this purpose, after the introduction, the article is divided in 4 more sections and completed with supplementary materials. Section 2 presents the materials and methods used in the research. It presents first the framework used (Design Research Methodology - DRM), the aspects of strong sustainability retained and then our three-steps methodological proposal named Design for Strong Sustainability (DfSoSy). Section 3presents a case study as an application of the DfSoSy method in a pedagogical workshop. The results, limitations and perspectives of the DfSoSy methodology are then discussed in section 4. Section 5 presents the conclusions of this work.

2. Materials and methods

The Design Research Methodology (DRM) proposed by Blessing and Chakrabarti (2009) has been chosen as the supporting framework for this research project. The DRM consists of four stages that are adapted to our purpose of implementing a design process in the SoSy paradigm (Fig. 1).

The first stage, Research Clarification (RC), consists in the literature analysis. In this stage, a short review of sustainability and strong sustainability paradigms has been performed in order to identify an adequate characterization to be used to further build design guidelines in a socio-technical-ecological framework. The major question addressed at this stage is: what are the elements that make it possible to characterize SoSy?

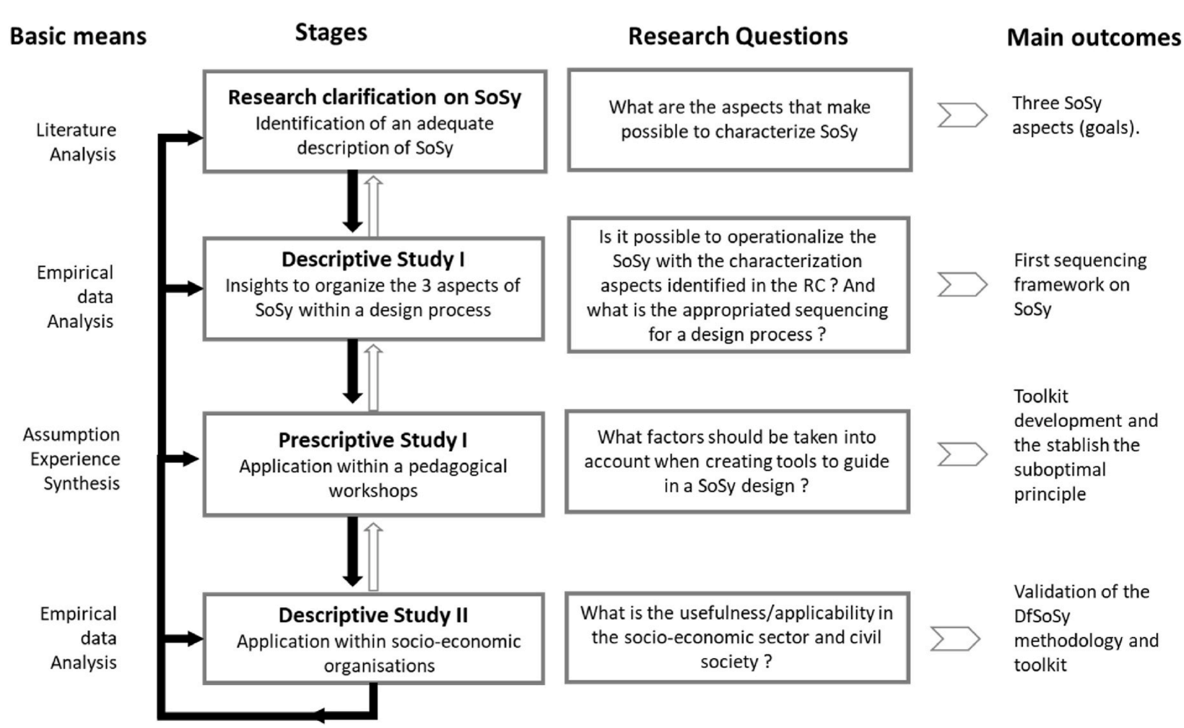

Fig. 1. DRM Framework adapted for the development of the new DfSoSy methodology.

The second stage is the Descriptive Study I, which consists in an empirical data analysis. This stage aims at increasing the understanding of factors that provide a successful design, such as the addition of supporting artefacts or guidelines. This second stage addresses research questions concerning (1) the possibility of operationalizing the SoSy with the characterization elements identified in the first stage, and (2) the appropriate sequencing for which scope of intervention in the design. Hence, in this stage, the different aspects of SoSy identified previously are organized into a design sequence.

The third stage is the Prescriptive Study I that aims at putting the proposed methodological framework to the test. This stage answers two research questions: What factors should be taken into account when creating tools to guide SoSy design? Application tools (schemes and toolkits) have been developed for this purpose. Moreover, an evaluation of the usability and applicability of the proposed supporting artefacts (and guidelines) and their usefulness has been done.

Finally, the last stage is the descriptive Study II focused on socio-economic organization applications with the research question: What is the usefulness/applicability in the socio-economic sector and for civil society? In this stage, the schemes and toolkits are used in design activities with different type of participants (eco-village and industry) and the influence of the use of the artefacts and guidelines are evaluated regarding the SoSy aspects of the final designs proposed by participants.

The build-up of the Design for Strong Sustainability DfSoSy model has been matured during the Descriptive Study I and Prescriptive Study I that will be presented in detail in this paper.

2.1. Research Clarification: identification of an adequate description of strong sustainability for design goals based on a scientific literature

To identify an adequate description of SoSy to be implemented with design guidelines a critically analysis and examination of the literature on the main ideas and relationships in the topic of SoSy has been carried out. According to Snyder (2019), this can be useful when the purpose is not to cover all articles ever published on the topic but rather to combine perspectives to create new theoretical models. Therefore, a selection of multidisciplinary works related to SoSy has been performed from a wide range of different fields and perspectives (Grant and Booth, 2009; Saunders and Rojon, 2011; Snyder, 2019). A selection of 15 scientific works from economic, sustainability, management, political science, philosophy and innovation research streams was collected. The coupling of diverse research streams is intended to propose a holistic conceptualisation of the SoSy paradigm.

In line with the aims of this paper, the selection of articles was chosen and built a sample according to the following criteria. For the first section, the selected articles are mainly devoted to the strong sustainability knowledge. The keyword "strong sustainability" was used in French and English: or the two words in one sentence (i.e., we choose to adopt a strong or a weak conception of sustainability). Integrative literature review was conducted (Snyder, 2019), as it is a methodology for research that can help to provide an overview of areas in which the research is disparate and interdisciplinary. Only peer-reviewed papers from indexed publications were selected.

Since the term "Sustainable Development" was first coined in the Brundtland report in 1987 (WCED 1987), various scientific trends have embraced this concept and proposed complementary descriptions. In economics, the model of the three capitals is often used where "Humanity" is a system consisting of an aggregate of a social capital representing Humans in society, an economic capital representing Human wealth and a natural capital representing Humans' environment (Pearce et al., 1989). Within this description, weak sustainability assumes that natural capital and manufactured capital can be substituted as it considers that they generate similar kinds of well-being (Ekins et al., 2003; Neumayer, 2003, 2013). In weak sustainable development, the total value of the aggregate stock of capital should be at least maintained for the sake of future generations (Solow, 1993). Within the model of the three capitals, a definition of "Strong Sustainability" (SoSy) is found in the article of Turner et al. (1993), who describes the SoSy paradigm as an interpretation of Sustainable Development, where substitution between different forms of capital is not a valid assumption to make. Daly (1992) and Georgescu-Roegen (1971) compare the economic process to the entropy of a thermodynamic system: in order to produce, it continuously draws on material and energy sources of low entropy and transforms them into high entropy, in the form of effluents and waste released into the biosphere. The uses and transformations of materials and energy by the economic system reduce the quantity available. In the field of environmental ethics, Konrad Ott (2009) suggests that describing SoSy through three capitals (natural, social and economic) even under a condition of equilibrium between capitals such as the Triple Bottom Line model proposed by Elkington (1997) is too limitative to describe a strong sustainability paradigm. In particular, the "capital approach" hardly express internal dynamic changes and interactions between capitals that are essential in SoSy paradigm. In other words, the "capital approach" relies on aggregated capitals that do not leave space for interactions between components (Wu, 2013). Some elements of the natural capital stock cannot be substituted (except on a very limited basis) by man-made capital and the maintenance of the natural capital stock is a condition for the strong version of sustainable development (Pearce et al. (1989, 1990), Pearce and Turner (1990), Victor, 1991; Munda, 1997; Özkaynak et al., 2004). Some of the functions and services of ecosystems are essential to human survival, they are support services such as biogeochemical cycling and cannot be replaced. With such dynamic aspects, natural capital can hardly be viewed as a mere stock of resources but rather as a complex system that provide human society directly and indirectly with a wide array of functions and services (Ekins et al., 2003; De Groot et al., 2003). Döring and Ott (2001) proposed three guidelines for SoSy development. First, "resilience" which relates directly to the preservation of natural capital, especially from a functional point of view (Döring and Egelkraut, 2008). Inter and intra-generational equity and ecosystem resilience were added to this definition (Devine and Rigby, 2004). Second, "sufficiency" which refers globally to the satisfaction of the basic human needs of all and, in relation to industrialized countries, to the problem of quality of life, new models of wealth and post-material lifestyles (Jungell-Michelssen and Heikkurinen, 2022). The third guideline, "efficiency" which refers to the economic dimension or environmental progress in the use of natural resources. Besides, Raworth (2012) proposed an extension of the use of the planetary boundary concept to include social objectives in the context of sustainability and has produced a framework defining a "safe and just operating space for humanity" known as the "Oxfam doughnut" that Dearing et al. (2014) transposed to a regional scale. In such description, the economy is no longer considered as an objective but as a mean integrating components that allows Humanity to thrive (Rupprech et al., 2020).

According to the above literature, the SoSy paradigm as a conceptual framework is a topic that it seems to be unaddressed in the scientific literature. This article proposes a methodology to help designers integrate the aspects that characterize strong sustainability into a design process.

In this paper, this was achieved by identifying specific SoSy elements, integrating them into a design framework and then testing them. Therefore, to overcome the limits of the "capital approach" to describe the "Humanity" system we propose to describe the system as a "Milieu" that comprises "Actors" that are "Humans" and "non-humans", who simultaneously observe and are part of biodiversity, interacting with the techno-diversity that shapes its Milieu (Petit and Guillaume, 2018; Droz, 2021). Fig. 2 presents a schematic representation of the Milieu as considered in our work.

In order to make it useable in a context of design process, the "Milieu" is situated meaning that it has a dimension and a location (physical environment). Indeed, innovation studies have shown that innovation is highly dependent on context as networks tend to be

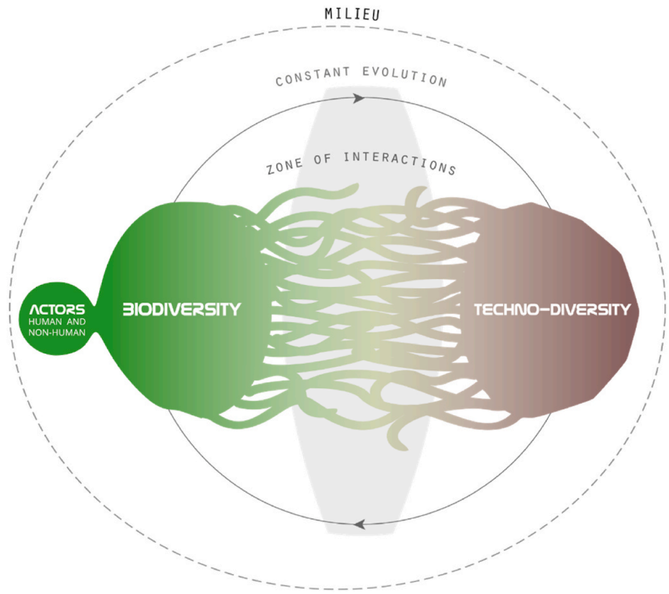

Fig. 2. The Milieu concept representation in a design for strong sustainability context, author's proposition.

facilitated by geographical proximity and decision making is influenced by local customs, traditions or practices (Chaminade, 2020; Edquist and Johnson, 1997). "Actors" are part and therefore interact within the "Milieu" and with components outside the "Milieu". The concept of milieu it is related to the field of ethics, it help us understand that our choices become the choices of a multi-species community. Droz (2021) proposes to see the milieu concept as an intermediate layer between our point of view and the environment, which we cannot access directly and neutrally. We cannot live outside the environment, but we perceive it and act within it as a milieu charged with meanings and values. The concept of milieu makes possible to complexify what is meant by development, by not limiting it to environmental standards but opening it up to its social and economic dimension (Petit and Guillaume, 2018).

The interactions in the milieu are essential in the biochemical cycles (Turner et al., 1993) and can take place in short-, long- and longer-term perspectives (Lozano, 2008). These complex interactions go beyond the direct utilitarian view of nature as a resource for humanity (Rupprecht et al., 2020). The regenerative capacity of biochemical cycle must not be exceeded in order to keep their environmental function intact (Goodland, 1995; Hueting and Reijnders, 1998). Thus, a "regeneration" is associated to the description of the "Milieu" in order to take into account evolving events (increase, decrease and cycles) related to interactions between "Actors". Finally, similarly to the Planet Boundaries approach (Steffen et al., 2015; Rockström et al., 2009) and the "Safe and Just operating space" (Raworth, 2012) the overall carrying capacities of the "Milieu" is also considered in our characterization of SoSy. Therefore, the concept of "Safe and Just space" is considered as the third aspect to take into account in a SoSy framework.

The next step to build our model of design methodology for Strong Sustainability relies on a coherent and integrative organization of these three aspects of Strong Sustainability find in the literature ("Milieu", "Regeneration", "Safe and Just operating space") into a process to create interaction between biodiversity and techno-diversity in a strong sustainability context.

2.2. *Descriptive study I: insights to organize the aspects of SoSy within a design process*

The process of design, also known as designing, is often described as an iterative process in which the need, or problem, is understood as the proposition, or solution, is generated and evaluated (Wynn and Clarkson, 2005p.41). Clarkson and Eckert (2010) have defined a design process as a complex entity that consist in both the actions to be carried out and the observable results of the actions (Clarkson and Eckert, 2010). One action leads to the next action and no action is initiated unless motivated by another action or an external driver or constraint. A design process is seen as a network of actions with causal connections between the elements. Drivers and constraints influence the specific characteristics of a design process. Clarkson and Eckert (2010) express that design processes are not deterministic. As a result, each design process is unique; however, common drivers and constraints can lead to similar characteristics in different processes. These similarities are design patterns i.e., elements of process behaviour that may be shared with other processes.

Designers are encouraging to follow systemic procedures where the design problem is supposed to be fully understood through intensive analytical work preceding the generation of solutions concepts (Cross, 2000). As a result, the models tended to suggest a basic structure of main steps to the design process. Therefore, modelling a new design method in SoSy is codifying the steps or the key phases in a design solving process for this new paradigm or context.

Prescript models illustrate and help incorporate increasing complexity of design problems. As revealed by the design methodological framework proposed by Gomez Castillo et al. (2012) that integrates traditional problem-solving design method and extensive use of qualitative methods, as user context research tools (i.e. social mapping or participatory appraisal). The result is a design process that encompasses five iterative stages.

Along with the awareness of sustainability challenges, authors have adapted and proposed design processes taking into account sustainability aspects. For instance, the Double Diamond model by the UK Design Council (2007) is a generic model that focused on the visualization of the state of mind of designers (divergent and convergent thinking) during four steps of a design process (Discover, Define, Develop, Deliver) from the problem to a solution. Divergent thinking is associated to creative steps that generates knowledge, solutions, ideas and convergent steps are associated to selection and decision making.

Generally used as a product-centric design process, Clune and Lockrey (2014) applied it to address sustainability challenges taking advantage of its flexibility to adopt multidisciplinary and integrated approach (Fig. 3). Moreover, Gomez-Castillo et al. (2012) proposed a design process made of five iterative stages that integrates traditional problem-solving design method and extensive use of qualitative methods, as user context research tools (i.e., social mapping or participatory appraisal).

To build our methodology of design process for Strong Sustainability, the three selected aspects of SoSy (Milieu, Regeneration, Safe and Just operating space) have been organized based on the following insights on the evaluation and decision making in innovation processes (Duffy and Andreasen, 1995; Derelöv, 2009). On one side, the evaluation of a design solution implies an assessment of its value made from explicit goals -in this case the three aspects of SoSy framework-. On the other side, making a decision is about selecting between a number of alternatives (Derelöv, 2009) -in this case between performance and robustness-. Usually, in product or service design, maximization of the performance and increase of the robustness are two conflicting objectives, which means that a trade-off exists between robustness and performance (Kitano, 2004). When looking for the performance of an activity, indicators to be maximized have to be defined. Then, the activity is controlled based on these indicators. When looking for robustness of an activity, the functions of the activity have to be defined and kept active. Kitano (2004) defines robustness as a property that allows a system to maintain its functions against internal and external perturbations. In biological systems, robustness facilitates the evolvability of complex dynamic systems. Evolution, given enough time, might select a robust trait that is tolerant against environmental perturbations. This interlinks the properties of robustness and evolvability. Systems that are

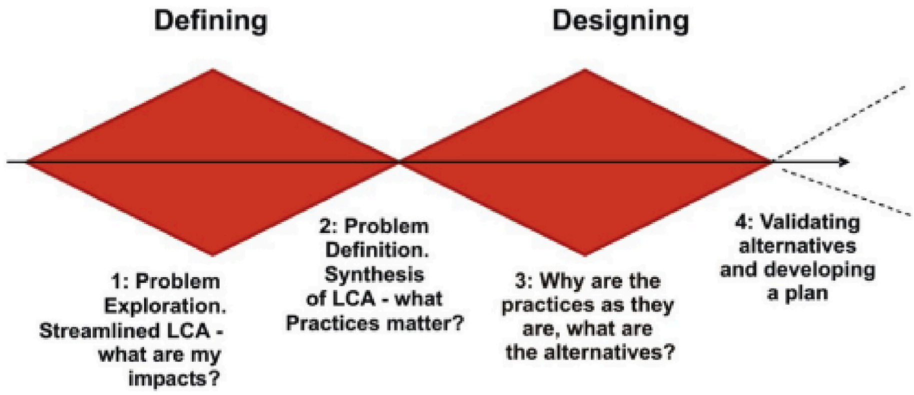

Fig. 3. The Double Diamond method of life cycle and design thinking (Clune and Lockrey, 2014).

robust involve intrinsic trade-offs. Enhanced robustness against certain perturbations might be balanced by extreme fragility elsewhere. At first sight, these robust yet fragile systems might be perceived as sub-optimal systems from the viewpoint of performance while they are satisfying systems from the viewpoint of functionality. Hamant (2022) made the parallel between robustness in biological systems and robustness in technical system, urging to seek for sub-optimal, yet satisfying, solutions. Therefore, applying SoSy framework implies relying on the properties of robustness rather than those of performances as in the traditional design process. This approach is inspiring to drive the decision-making steps of the design process that is prototyped in this article.

Based on the Research Clarification step, the three iterative and complementary steps chosen to describe strong sustainability applied to the action of designing are “Situate”, “Intertwine” and “Balance”. These steps are detailed hereafter. Within this DfSoSy methodology, these three iterative steps encompass actions to guide designers from an insular scope to a sociotechnical ecological system as mentioned by Ceschin and Gaziulusoy (2019). The use of this description of DfSoSy has been tested within two complementary setups within design workshops with students. A first setup done within the Descriptive Study I of DRM enabled to validate that an understandable description of SoSy was made using this scheme. Ideas proposed by students within the DfSoSy scheme were indeed fulfilling more aspects of Strong Sustainability than ideas provided without any framework (Escobar et al., 2023).

Finally, to anchor the iterative DfSoSy process into existing design process schemes, a hybridization of the double diamond framework (Clune and Lockrey, 2014) that highlights divergent and convergent thinking of the iterative DfSoSy process has been proposed (Fig. 4). Each step ends with a deliverable, deliverable 0 (D0) for the initial solution, deliverable 1 (D1) for the “Situate” step, deliverable 2 (D2) for the “intertwine” step and deliverable 3 (D3) for the “balance” step deliverable and the final deliverable (FD) for the final proposition. In order to articulate the co-existence of these three aspects of SoSy during the whole action of producing design for strong sustainability systems, the principle of sub-optimality is highlighted as a decision principle and the thinking framework is associated to the enabling abilities in a design methodology (Eckert et al., 2003).

The following paragraphs present the steps in line with the double-diamond framework established. Each step is supported by key-factors specifically proposed for the DfSoSy methodology. A key-factor is “*an influencing factor that seems to be the useful factor to address in order to improve an existing situation*”. (Blessing and Chakrabarti, 2009).

a) Step 1: Situate

The integrative thinking (Poth, 2018) is introduced. The aim is to facilitate the integration of all three dimensions (economic, environment, social) into situated solutions. Integrative thinking favours the maintenance of opposing ideas in mind simultaneously in order to creatively generate superior solutions: for instance, addressing the dualism of human/environment (Petit and Guillaume, 2018), human/animal (von Uexküll et al., 2010), nature/culture (Descola,

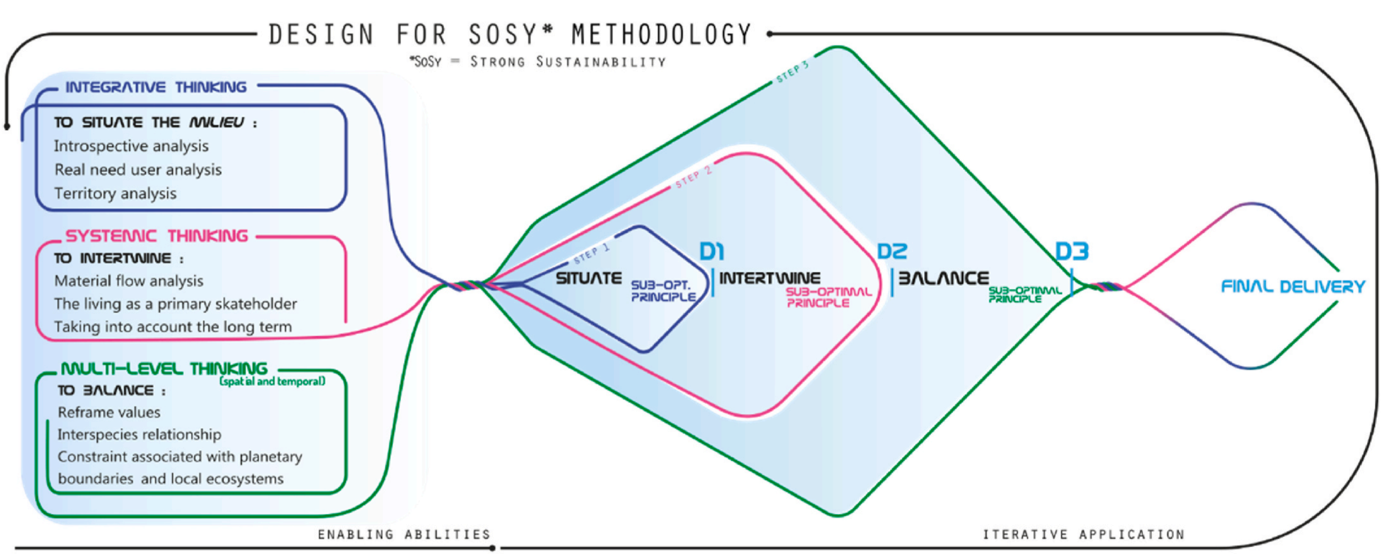

Fig. 4. DfSoSy methodology by the positioning of each step according to the aspect of SoSy, its thinking approach, and key factors or abilities.

2013) to overcome ethical notions of strong sustainability. In this step, designers work in a user-centred focus with a territorial approach, which means placing the user in its space and time. During this step, there are three key factors supported by guide-sheets given in the Supplementary Materials #1 (SM1):

Key Factor 1: Introspective analysis.

Prior to the activity of "designing", a self-reflexiveness phase is practice using an awareness Tool. With a focus "learning by doing", it raises awareness of the challenges of collective damage to the planet. This activity allows understanding the problems of our own way of functioning and allows envisaging the changes by following the sub-optimality guideline, previously mentioned. No canvas is used for this factor.

Key Factor 2: real user need recognition. Name of the canvas: User needs analysis.

It consists in the description of the user needs analysis, with a critique perspective differentiating desire of real need. Then the user needs are classified into three levels: essential, important and interesting.

Key factor 3: Territory resources and needs analysis.

The guide-sheets aim to facilitate the identification of human and non-human actors. The user is situated within its territorial context. Resources, needs, actors are identified within the territory.

b) Step 2: Intertwine

The systemic thinking is introduced (Von Bertalanffy et al., 1993). The aim is to facilitate linking/connecting stakeholders through the understanding of their influence on each other and through the creation of value for each of them. Facing a scarcity of resources, an abundance of interactions between humans and non-humans can be resourceful to create new solutions. In this stage, the scope of design is extended from a product to a system by taking advantage of the territory's resources: systemisation/networking to limit individual impact. During this step, there are three key factors supported by guide-sheets (SM2):

Key Factor 1: material flow analysis. Name of the canvas: Actor mapping.

Based on the situated resources and needs analysis performed during the "Situate" step, a diagnostic of the relationships between actors and stakeholders is carried out through a mind map. Links are identified as rather positive or negative. This visualization facilitates the emergence of solutions based on interactions.

Key Factor 2: Stakeholder analysis. Name of the canvas: Decentring.

To favour the analysis of non-human stakeholders, designers are forced to empathize with non-human stakeholders. Using a role-playing game that puts the designer in the shoes of non-human stakeholders such as an earthworm, a fish, a bird or a vegetable that are likely to be impacted by the design project.

Key Factor 3: Considering the long term. Name of the canvas: Present and future generations debate.

Taking account of the long term with a decision-making tool including futures generations concerns, it has the ability to integrate in the short-term the interest of future generations. (Hara et al., 2019). As part of the role-playing game, designers are asked to imagine the impact in present time but also in the future with regards to the short-term and long-term of natural cycles.

c) Step 3: Balance

The fractal thinking (West et al., 1995; West et al., 2008; Taddei, 2022) is favoured in this step. As described by Raworth (2012), humans should be situated in a "safe and just space" between an acceptable social floor and a sustainable environmental ceiling. Designers are asked to consider that the economy is a means of fulfilment of an acceptable human social condition within the constraints of the earth system. These constraints are associated, on one side, with the limits of local and global ecosystems and, on the other side, with the social needs. Designers are forced to consider multi-scale relationships through three key factors supported by guide-sheets (SM3).

Key Factor 1: Reframe values flow, name of the canvas: Strong Sustainability Business Model.

To specifically address the tension between Strong Sustainability and Economics. A Strong Sustainability Business Model Canvas (Brozovic, 2020) is used to force designers to focus on the value proposition targeted to nature, beyond financial aspects. This canvas presents the living is a primary stakeholder and, consequently, reframes value flows within the business model with the constraints linked to the limitations of natural resources which forces in turn to search for more solidarity and cooperation strengthening resilience and robustness.

Key factor 2: Interspecies relationship, name of the canvas: Cosmology of the project.

Technical choices form a link between actors within the milieu. In this step, the evaluation of the project (technical or not) regarding the interspecies relationships is essential to rethink the role and the place of technology. The interspecies relationship is explained throughout the classifications of ontologies (worldview, cosmology …) as totemism, animism, analogism and naturalism proposed by Descola (2013). Five dimensions are proposed to explore the interdependent relationships of the proposal: the interspecies user, sociology, techno-diversity, the living system and the planetary system.

Key factor 3: Assessing the constraints of global boundaries and local ecosystems. Canvas 3: Safe and just operation space.

The objective of this last part is to position the project of the project in a subjective way regarding the 'doughnuts' elements. The corresponding guide-sheet helps identifying the social ceiling that designers do not want to exceed and the environmental ceiling (planet limits), the most at risk.

At the end of these three steps, the guide-sheets intend to force designers to drive their designs towards a SoSy paradigm. To validate that this process and the supporting guide-sheet can be used in design activities, this DfSoSy toolkit has been tested within a design workshop with students.

The workshop learning method puts future designers in a professional situation, enabling them to deal with a project as a whole and as part of a team. Moreover, the workshop format allows theoretical input to be interspersed with moments of creativity. This workshop stands for the Prescriptive Study I (Fig. 1) within the DRM framework.

Young people are already aware of some aspects of sustainability related to sustainable development (SD) and eco-design and therefore to the weak sustainability approaches (Perpignan et al., 2018). Nevertheless, strong sustainability is not yet well-defined in the existing literature. Moreover, the existing literature shows that "awareness" might be a key to professional commitment, as pertains to the "meaning of work" (Mao et al., 2020; Dimitrova et al., 2021), so it is a mission of higher education to link "awareness" and "skills" to promote the use of "skills" in the service of SoSy.

As mentioned previously, following the descriptive study I, a second setup done within the Prescriptive Study I enabled to identify milestones within the DfSoSy process that need specific guide-sheets to be more easily understood. These guide-sheets are gathered with the DfSoSy toolkit (CC BY-NC-ND 4.0). The next part presents the Prescriptive study I.

3. Results

In the Prescriptive study I, a workshop application was performed. During 4 subsequent days (36 h in total), twelve design students (L3) were enrolled in the workshop. The pedagogical objectives of the workshop were "Understanding and applying elements of strong sustainability" comprising.

- o Three aspects: Milieu, Regeneration, Safe and Just Operating Space
  - Real need analysis

- Integrating living being
- Economy taken as a means

o The iterative stages of the creative process: situate, intertwine, balance

- Sub-optimality selection principle

o A new thinking framework

To ensure that the workshop ran smoothly, a roadmap was drawn up. It is structured into 4 days incorporating the three stages of the methodology (step 1: situate, step 2: intertwine, step 3: balance). A preliminary preparation stage and a final restitution stage complete the schedule. Fig. 5 summarizes all these stages, highlighting the main points in terms of key factors and deliverables. This schematization is also intended to provide a basis for replicability in the use of DfSoSy methodology tools.

In teams of 2 or 3, students had to follow the DfSoSy process. In this paper, the design process of one specific team of three students, called focus team, will be detailed to illustrate the influence of the DfSoSy model and supporting guide-sheets on the design activity of the students. In particular, each deliverable (D0, D1, D2, D3 and FD) will be presented regarding the DfSoSy model. The deliverable D0 is identified as the initial solution, i.e., the solution given without following the DfSoSy process. In the workshop setup, the students were not aware of the scope of the workshop before the beginning.

Then, design brief "design a food preservation system" was given to the students at the beginning of Day 1, and they were given 1 h to imagine, individually, a concept to address the brief. Then, in the following of the workshop, students gather into teams of two or three.

To guide them to design in a situated territory within the duration of the workshop, an eco-village with detailed description reports available online was selected by the teaching staff (Collectif de l'Oasis du Coq à l'Âme). The subject concerns a problematic given by an ecovillage. In addition, prior to the workshop, interviews of stakeholders living in this area were performed by the teaching staff. With these interviews and the reports available online, students got access to complementary information related to the selected territory.

In the individual deliverable D0, a description of each individual concept presenting the Where, What, Who, Why and When is provided with a few iconographic representations. The initial individual concepts

Table 1
Initial individual concepts from the three-team members.

REFERENCE SITUATION	
D0 Concept of the student 1	Ground fridge: by Dutch designer Floris Shooderbeck, an underground fridge for des communities.
D0 Concept of the student 2	Grandmother's methods: drying, salting and storing underground. Showing that food preservation does not necessarily require high technology or additives, but is based on simple principles.
D0 Concept of the student 3	Granny's kitchen: For users who want to learn how to cook, eat seasonal, quality food all year round and send the preparation to someone else. Themed cooking workshops and a preserving area to take home by subscription. A room is set aside for equipment, and an animator explains the process of preserving in jars. These will be sent by parcel as a gift from Granny's kitchen to the person chosen by the user.

Fig. 5. Roadmap for the application of the DfSoSy methodology.

from the three-team members are presented inTable 1.

After this preliminary session, the "Situate" step was initiated as a group activity through an *Introspective analysis using the* "Climate Fresk©" (https://fresqueduclimat.org/) as awareness tool. After going through the whole Climate Fresk ©, students were asked to express emotions and actions regarding the setup. As a closure of day one, a short course detailing sub-optimality as decision principle (Hamant, 2022) was presented within the DfSoSy framework.

On day two, the "Situate" step continued with a short-course presenting the "Milieu" as a situated system that comprises "Actors" that are "Humans" and any other "bio-geo-component and opening on an activity dedicated to the analysis of needs and resources. Based on the territory description given by the teaching staff, students were asked to analyse the territory with regards to the materials, human and economic resources available and also with regards to the interactions between these identified resources. This information was visualized on a mind-map. In addition, the design brief that expresses the user needs and each individual D0 concepts has been analysed regarding the territory resources with the guide-sheet (SM1) that forces the designer to categorize the needs into three levels of importance (interesting, important and essential). The resulting categorization of needs provided by the focus team is detailed in Table 2. Three essential needs were highlighted considering the conservation issue: Vegetable/fruit production, Canning (glass beakers) and Compost for fertilizer.

By noon in day two, as a closure of the "Situate" step, each team was asked to make one proposal concerning their essential needs (D1). The essential needs chosen by the focus team for the next steps is "vegetable and Food production".

In the afternoon of day two, the step "intertwine" was initiated with a short course on systemic thinking as a process to link components together followed by an activity dedicated to the identification of stakeholders of the proposals D1. Using the Actors Mapping Canvas (SM2), the stakeholders related to the specific aspects of the proposal are identified (Table 3) and linked together.

Later, a collective role-playing game was organized as energizer using the canvas: *Present and future generations debate* (SM2). Inspired from Future Design approach (Hara et al., 2019), students were divided into 3 groups and a debate discussing each proposal was played between one group representing the current generation and one group representing the future generation, the last group being in charge of taking notes of the debate to be communicated to each team afterward.

Table 2
Results of the Step 1: Analysis of needs and identification of the local players.

RESULTS OF THE STEP 1: ANALYSIS OF NEEDS	
Classification	Needs identified
Interesting	- Produce plant milk/yoghurts, jams (workshops) - Breeding - Offering workshops to outsiders
Important	- To sell production (to invest in the community) - Invest in underground conservation methods - Rainwater tanks
Essential	- Vegetable/fruit production - Canning (glass beakers) - Compost for fertilizer

IDENTIFICATION OF THE LOCAL PLAYERS INVOLVE IN THE PROPOSAL	
Specific elements of proposal D1	Local actors
Construction, source of materials? Who builds? Tools?	Resale shop or community recycling community volunteers loan of tools by local residents
Durability, maintenance	barn caretaker participatory workshop maintenance
Jar provenience	Investment donations/loans local residents
Sterilization awareness workshop	

Table 3
Evolution of the focus team deliverables.

REFERENCE SITUATION SELECTED	
D0 Concept 3 (selected)	Granny's kitchen: For users who want to learn how to cook, eat seasonal, quality food all year round and send the preparation to someone else. Themed cooking workshops and a preserving area to take home by subscription. A room is set aside for equipment, and an animator explains the process of preserving in jars. These will be sent by parcel as a gift from Granny's kitchen to the person chosen by the user.
DELIVERABLES DEVELOPED USING THE METHOD	
D1: Vegetable Garden	Producing differently, a market gardening system by season which includes two watering systems (one by porosity and the other by a perforated hose) using water from rainwater harvesting.
D2: The barter cupboard (First draft end of day 2)	Students thought for three steps for the development: (1) recovering/buying a second-hand wardrobe, (2) personalise the cupboard aesthetically and with educational notes (how to store food, associated risks and a note about thinking of others) (3) assign a member of the community to clean up and compost what has not been conserved.
D2: The barter cupboard (Final draft, day 3)	Addition of a point-of-sale advertisement for a food that will soon rot. Consideration of the management of food intake, with meetings for products not collected during the week and decisions on distribution or composting.
D3: Convivial and collaborative meal	As a major seasonal harvest approaches, a protocol is put in place: A call for volunteers goes out via social networks, and following the harvest there is a distribution for local residents and a collaborative cooking workshop with surplus stock. A convivial meal and, if there is a surplus, distribution to association members.
Final deliverable: "Seasonal Event"	To absorb excess of harvesting. For that, the ecovillage calls on the help of outside individuals (subscribers). It consists in organizing, at the end of the harvest, a cooking workshop with the volunteers, followed by a tasting of the meal in the barn.

As an opening activity in Day 3, a short-course illustrating "non-humans as stakeholders" was provided. Then teams were invited to consider non-human stakeholders in their proposals (guide-sheet in SM2).

Thus, students had to reformulate their scenario proposals according to the local actors and stakeholders identified. It results in the deliverable D2.

In the afternoon of Day 3, the "Balance" step was initiated through a short-course introducing the planetary boundaries. This step favours the gathering of the different aspects of the proposals through analytical grids. The first grid is related to the Doughnuts economy, the safe and just operating space canvas (SM3). The teams were asked to identify if their solutions respect the social limits and the and the constraints of local and global ecosystems, in others words, that the solutions are compatible with low environmental impact and high social well-being (safe and just space from [Raworth, 2017]).

The second analytical grids are the cosmology canvas. In the sheet presented in SM3, the students used an anthropologic approach, to put the project into the five dimensions or perspectives. The objective is to pay attention to the inter-species relationship decisions, in order to create symbiotic or mutualistic links between the stakeholders in their milieu. Below, a list of elements made by the focus team that should be taken into account in the proposal.

- User dimension: eco-village residents; 30 adults and 13 children
- Social dimension: inhabitants and those of other eco-villages, second-hand goods dealers

- Technical dimension: carpentry, conservation workshop, barn (physical structure)
- Other living beings: animals that feed on compost, fruits and vegetables that are not thrown away.
- Earth system dimension: soil, watercourses, groundwater.

At the end of Day 3, the teams were asked to develop their proposals that constitutes the deliverable D3 (Table 3). To conclude the workshop, the teams performed a self-assessment of their proposal using the Strong Sustainability Grid. To do so, they have to analyse if their solution is consistent with the three aspects of the strong sustainability framework; milieu, regeneration and safe and just operating space respectively dealt with the three-step DfSoSy methodology (milieu, Intertwine and balance). Moreover, they assessed their solution considering the three approaching ways through integrative, systemic and multidimensional thinking (SM4). The different deliverables produced by each team are provided in Table 3.

As shown in Table 3, as the workshop progresses and the theoretical inputs are delivered, the scenarios proposed evolve. Indeed, at each stage, the future designers propose elements of their project that feed into the final version of their proposal.

In order to ensure that the various aspects of strong sustainability are taken into account, an evaluation of the proposals is necessary, and is presented in the following section.

3.1. Evaluation of the design model for strong sustainability paradigm

As the aim of the experiment is to make it possible to integrate strong sustainability issues into design projects, it is necessary to check whether the objectives have been achieved.

Two evaluation methods have been used Feedback on whether objectives have been met.

- Student self-assessment
- Experts' evaluation

3.1.1. Student self-assessment

In order to assess the integration of the three aspects of SoSy in their proposals, students were asked to self-assess their concepts following three questions related to these three aspects in an assessment grid (SM4). The students were given a 4-level Likert-scale to answer these questions. Table 4 presents the questions and the scales for the self-assessment.

By way of illustrations, the results of the focus team's self-assessment are presented in Fig. 6. Each student answered the questions in Table 4 according to the proposed scale.

The results of the self-assessment Fig. 6 (6a)show that the students consider that they have taken into account the three aspects of strong sustainability in a correct manner; the scores are on average around 3. It appears that the students were able to grasp the aspects of Milieu and Safe and Just Operating Space more easily. The regeneration aspect seems to have been less integrated by the students according to their self-assessment. The positioning of their feelings on the representation of interlaced aspects in Fig. 6 (6b) confirms this.

Table 4
Question and scale for student self-assessment.

Questions asked	4-level Likert-scale
- How is your concept related to the aspect of "Milieu"? - How is your concept related to the aspect of "Regeneration"? - How is your concept related to the aspect of "Safe and Just operating Space"?	1 Not related at all 2A little bit related 3 Correctly related 4 In total correlation

3.1.2. Experience feedback from the experts

Through the analysis of this experience, the achievement of the pedagogical objectives forecast can be assessed.

After following the DfSoSy model, the task clarification corresponded to the SoSy aspects (goals) in a conceptual design stage. Students created a new concept of a project with the use of the intended support (guide-sheets in Supplementary Materials SM1, SM2 and SM3), which is expected to encourage and support problem definition. A first evaluation (SM4) of these supports completed by the students' shows that they seem relevant. Indeed, the students' proposals progressively evolve, from a concept proposition, focusing on the designer motivations to real user needs taken into account. This led to a complex project with a holistic perspective, including the three aspects that characterize strong sustainability.

Indeed, the analysis of the students' proposals shows that they respect the strong sustainability paradigm, as they treat the living as non-substitutable, both in the production of goods and as a provider of utility and they stablish a full integration of three dimensions of sustainability into the center of the new proposition. They also contributed to local socio-technical ecological robustness in the ecovillage food system.

In fact, the result of a higher robustness rather than performance is a concern they have addressed, as they have adopted the elements of sub-optimality principle, moving from technocentric solutions to solutions centred on their milieu. Enhancing resilient collective behaviour, they have favoured group resilience strategies over individual comfort. For example, focusing on bringing together the actors around the eco-village, adapting them to their milieu cycles.

After the iterative process in STEP 1 (situate), students rethought the problem concerning the real needs of the eco-village by making better use of surpluses from certain crops. They noticed that "some harvests are so important that the community doesn't have time to consume them all, so one rots and goes to compost?". Thus, their final proposition was the creation of workshops for an outside audience during major harvests throughout the year.

Considering the Integrative Thinking associated to this first step, they expressed "a social project for sharing and coming together to raise awareness of harvesting and responsible cooking".

For the STEP 2 (intertwine), they declare: "the project allows the ecovillage to thrive over time. By opening up the ecovillage to people from outside to share and expand a way of living and thinking, and by attracting new members to the project-workshop, which is repeated according to the seasons."

Regarding the systemic thinking associated to this second step, the project brought together different players from different backgrounds and with different ways of life who can learn from each other.

It is important to remind that the student from the focus team who proposed the first chosen concept "Granny's kitchen" was blocked and could not plan to make it evolve, left the course at this stage. The left two students continued the study.

In the STEP 3 (balance) students said: "Makes good use of the entire harvest - Uses little energy -Restores a place to nature (harvested by outside volunteers)".

For the multi-level thinking associated to this third step, students wanted "a project that can be applied to other ecovillages, depending on the amount of harvest and the number of inhabitants. Adaptable because it's easy to set up and flexible".

The evaluation of the deliverables was carried out in accordance with the key-factors mentioned previously. These key-factors (Table 5) established the design elements as criteria that can be integrated into projects through the DfSoSy methodology, according to three SoSy aspects.

These criteria were used to evaluate individual deliverables 0 (D0) and final team's deliverables (FD). The criteria are assessed by awarding one point for each criterion met. If the proposal does not meet the criterion, it is given a score of 0. The final score is the sum of the score for

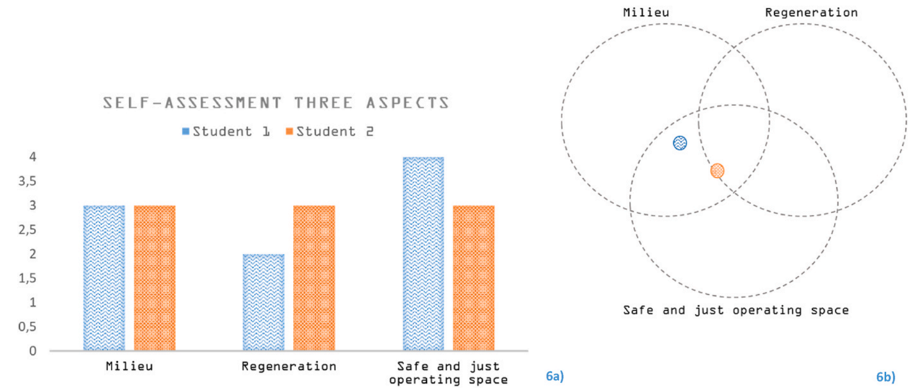

Fig. 6. Self-assessment of the integration of the three aspects of SoSy for the conception of a solution to the food conservation (6a) and the position of the student feeling considering the integration of the three aspects (6 b).

Table 5
Criteria for the evaluation of the 3 SoSy aspects.

Milieu	Regeneration	Safe and just operating space
real user need recognition	consideration of future and current human and non-human generations	awareness of social ceilings
local resources	link between actors	awareness of planetary boundaries
relation human and non-human/ ecosystem	Material circularity	economy as a means

each criterion, with a maximum of 9 points.

At the end of the scoring process, we propose the following analysis grid.

- If the score is between [0 and 3]: **poor** consideration of the aspects of SoSy
- If the score is between [4 and 6]: **satisfactory** consideration of the aspects of SoSy
- If the score is between [7 and 9]: **highly satisfactory** consideration of the aspects of SoSy

As it can be seen in Fig. 7, solutions proposed as D0 (the reference situation) (7a) were scored “poor” according to the criteria and final

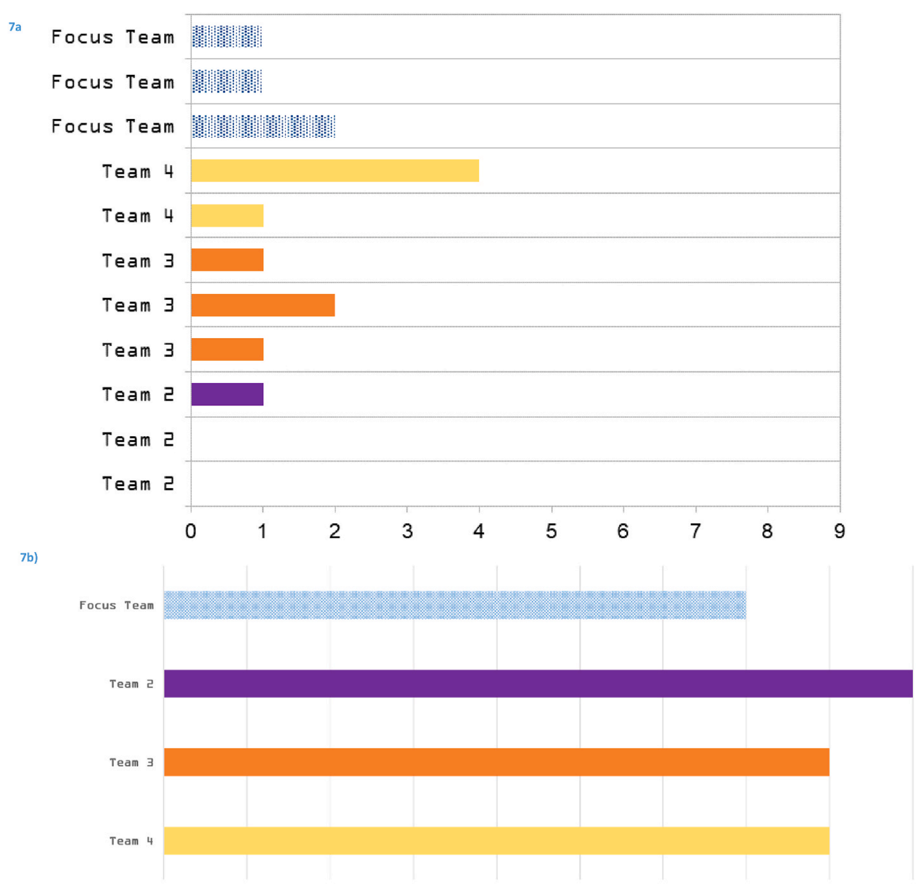

Fig. 7. Expert’s assessment of the individual proposals in the D0 (7a) and the teams’ proposals in the final deliverables (7 b).

solutions (FD) (7 b) were scored “highly satisfactory”. Therefore, it can be concluded that the ability of the DfSoSy methodology to assist understand and effectively apply the requirements or objectives of SoSy as highly satisfactory.

From all the feedback, self-assessment and deliverables, it can be concluded that the pedagogical objectives (“Understanding and applying elements of strong sustainability in a design process”) have been achieved. In fact, the understanding and application of the elements of strong sustainability throughout: (1) the operationalization of the three aspects (Milieu, Regeneration, Safe and Just Operating Space), (2) the implementation of the iterative approach based on Situate, intertwine, balance steps (3) the application of a new thinking framework.

4. Discussion

The pedagogical application demonstrated the potential of the DfSoSy methodology© for learning about strong sustainability and integrating the three aspects into a design process.

The perspective of the new strong sustainability framework is to create a baseline for goal setting and evaluation in the development of new solutions. In addition, it provides new tools for future and present designers to meet the new challenges of climate change and its systemic risks. In this sense, the methodology and its tool contribute to guide the creation of new curricula and a guide to include strong sustainability strategies for system change in companies.

Some limitations of this study should be highlighted, an important bias could question this analysis. Indeed, students are often in a position of applying methods provided by teachers by following the guidelines. They are attracted by the results associated with the assessments and grades they will obtain. They are more interested in this specific object and in pleasing teachers. To ensure that these aspects of sustainability are taken into account, surveys could be carried out with students in the coming months to check whether they have been able to implement these SoSy aspects in their personal or professional projects.

Moreover, in relation to the students’ personal experience, it is interesting to highlight the strong emotion to the point of tears felt by a student who described the DfSoSy process as a tool to address the environmental problem that is leading us to the loss of the planet’s habitability.

In addition, at this stage of DfSoSy methodology development, contributions can be emphasized to the theory and practice.

- To assist in the clarification and understanding of SoSy knowledge found in the literature review (Milieu, Regeneration, Safe and Just Operating Space).
- To assist in the application of the aspects that characterize SoSy, through the three actions to be taken at each stage iteratively (to situate, to intertwine and to balance).

Design for Transitions developed by Irwin (2015) is a design model that is at least partially the closest to the strong sustainability paradigm as it is in the socio-technical ecological level. Indeed, according to Ceschin and Gaziulusoy (2020), it is positioned within a technocentric and in the beginning of the earth-centred focus on framing the design problem. The design of the SoSy methodology enhances this approach because it allows; (i) to elucidate the real needs of human and non-human users, (ii) to integrate human and non-human stakeholders into the design process by decentering, (iii) support the assessment of social constraints (social floor) and (iv) support the assessment of ecosystem constraints (planetary boundaries). Elements which represent tools that allow a design approach beyond the instrumentalization of nature and its anthropocentric focus.

Besides, another contribution of our proposition is that it relies on the properties of robustness (the theory of sufficiency and resilience) rather than those of performances as in the traditional design processes (i.e., Ecodesign, Systemic Design, Transition Design).

To verify the replicability and transposability of the DfSoSy methodology, other applications need to be deployed. Hence, further applications proving the effectiveness and utility of the DfSoSy methodology© are in progress as multiples experimentations: (1) with futures designers or engineers in a pedagogic context of practical work, (2) in collaboration with industry, and (3) in participative design focus with an eco-village. The diversity of the audiences involved in these experimentations will help to conclude on the genericity of the methodology, or if adaptations are necessary to suit the problems submitted. In order to know the degree of persistence of the training on future design ideation activities, feedbacks after 6 months of the experimentation will be done.

5. Conclusion

In order to ensure a viable and deliverable future for all the living being in line with environmental issues and the planet’s boundaries, a paradigm shift in design methodology has been demonstrated. An analysis of the literature revealed a gap in Design for Sustainability (DfS) approaches. Indeed, there are no clear indications of a methodological approach or a design method for SoSy. In order to move towards a design methodology that integrate the challenges of strong sustainability, a Design for Strong Sustainability (DfSoSy) methodology © (CC BY-NC-ND 4.0) had been proposed. The foundations of the proposed methodology are based on an analysis of the founding concepts of strong sustainability led to highlighting three aspects characterizing strong sustainability (SoSy): the “Milieu”, the Regeneration and the Safe and Just Operating space. The challenge was to translate the SoSy aspects into useable knowledge and guidelines for more strong sustainable design, and to formalize a SoSy framework for its operationalization in design. Based on a three-step iterative design support process (situate, intertwine and balance) and its new thinking framework (integrative, systemic and multi-level), the Design for Strong Sustainability (DfSoSy) methodology © transcribes the three aspects of SoSy.

The major scientific contributions are.

- To assist in the clarification and understanding of SoSy knowledge found in the literature review (Milieu, Regeneration, Safe and Just Operating Space).
- To assist in the application of the aspects that characterize SoSy, through the three actions to be taken at each step iteratively (to situate, to intertwine and to balance).
- To take into account living stakeholders (human and non-human) in design models by a decentralization approach
- To integrate the properties of robustness rather than those of performances

The DfSoSy three-steps methodology has proven its effectiveness considering the integration of the 3 aspects of SoSy retained within an ideation design process in a context of design students’ workshop. To broaden the scope of the methodology, the ANR D-TechnoSS project is planning to apply it in the short term in the civil society sector (eco-village) and in the telecoms network sector with a major French company.

The characterization of the SoSy proposes a new framework for the organization of society, allowing to stop seeing the environment as an externality relegating our milieu as an economic cost; indeed, in SoSy economy becomes the means and not the objective. This new way of organizing society requires us to question our interdependence and co-evolution between human and non-human societies and ecosystems in time and space. In this manner, strong sustainability can be considered as a chance to sufficiently slow anthropogenic ecological degradation.

CRediT authorship contribution statement

Melissa Escobar Cisternas: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jenny Faucheu:** Writing – original draft, Validation, Supervision. **Nadege Troussier:** Validation, Supervision, Project administration, Funding acquisition. **Valerie Laforest:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Melissa Escobar reports financial support was provided by French National Research Agency. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2024.100224.

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