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Mapping causal networks from theories of change in sustainability projects: a software co-design process

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Envisioning trajectories towards sustainability encompasses enacting significant changes in multiple spheres (i.e., infrastructure, policy, practices, behaviors). These changes unfold within the intricate landscapes of wicked problems, where diverse perspectives and potential solutions intersect and often clash. Advancing more equitable and sustainable trajectories demands recognition of and collaboration with diverse voices to uncover meaningful synergies among groups striving to catalyze substantial change. Projects of this nature necessitate the exploration of varied tools and methodologies to elicit, convey, and integrate ideas effectively. Creating spaces for reflexivity is essential for catalyzing more meaningful impact as individuals engage in discussions aimed at sharing and questioning the coherence of their projects while forging synergies, identifying common objectives, and planning long-term outcomes. We present the initial phase of an endeavor in which we developed a software that elicits causal networks based on mapping relations between projects' actions and outcomes. To illustrate our approach, we describe the results of using this software within collaborative workshops with groups spearheading projects initiated by a government entity in Mexico City. By adapting elements of the Theory of Change model, this software transcends the dominant linear project logic by guiding participants in designing causation networks that unveil how different projects can articulate to identify potential common elements and find new possibilities for coordination among initiatives. We discuss the potential of such software application as a dynamic tool to guide and promote reflection and coherence when crafting projects that aim to more meaningfully address sustainability problems.

KEYWORDS

meta-graph software, sustainability projects, causation networks, Theory of Change, Mexico

1 Introduction

Designing and enacting trajectories towards sustainability entails articulating significant structural changes (i.e., transformative change Dupuis et al., 2023; Scoones et al., 2020) in infrastructure, policy, practices, and behavior (O'Brien, 2018). As these changes occur in entangled contexts of wicked problems (Rittel and Webber, 1973), diverse framings and potential "solutions" are always contested and influenced by many factors such as dominant interests and power asymmetries (Turnhout et al., 2020). Thus, promoting more equitable and sustainable trajectories necessitates working from and with diversity (in contexts, struggles, interests, positionalities, agendas, etc.), and to explicitly acknowledge that engaging with such plurality is the basis for finding more meaningful synergies between individuals or groups committed to catalyzing more significant changes (Caniglia et al., 2021).

Collaborative endeavors aimed at addressing sustainability problems entail engaging with the complex task of sharing, eliciting, and understanding how individuals differently frame the challenge at stake and the proposed strategies to address it (Charli-Joseph et al., 2023). Such different ways of framing an issue are determined by individual's particular interests, beliefs, values, life history, social relations, political orientation, etc. Thus, creating and implementing sustainability projects requires facilitating caring and respectful collaborative processes that can enable reflexive dialogues to understand different framings while co-constructing a common language and collective agreements. There are many efforts inspired by methodological approaches, conceptual frameworks, or particular experiences that seek to integrate diverse types of knowledge, interests, and needs into projects aimed at achieving significant impact towards sustainability (e.g., Participatory Action Research-Fals Borda et al., 2006, transdisciplinary co-production of knowledge Chambers et al., 2021, iterative learning spaces for reflection and engagement Binder et al., 2015). For instance, the Theory of Change framework is a dialogue-based process intended to generate a description of a sequence of events expected to lead to a particular desired outcome, with concrete impacts that are assessed through diverse indicators (Vogel, 2012). Generally, this process is depicted in a linear diagram where pre-conditions, inputs or requirements, activities or interventions, assumptions, outputs, outcomes, and impacts are captured.

However, there is still a need to enable spaces within a project process to reflect on how to co-design strategies for building alliances, implementing actions for addressing challenges at stake, and creating mechanisms to evaluate more intangible foreseen outcomes (Sol et al., 2018). Moreover, as the formation of intersectoral teams is often sudden and responds to urgent needs and/or circumstantial situations, many projects lack a coherent methodological design and clear planning of the participatory process and its different engagement phases and evaluation mechanisms (Merçon et al., 2018).

Enabling iterative processes to reflect on how change might happen and what influence is possible in specific contexts is a fundamental ingredient to collectively guide planned initiatives or projects, and adapt them according to emergent conditions and diverse needs and interests (Marshall et al., 2021). Ultimately, the importance of reflexivity in driving change (Dieleman, 2008) underscores the need to further develop innovative mechanisms that foster more meaningful engagement within projects focused on achieving lasting impacts towards sustainability.

In this paper, we present how we adapted components of the classical Theory of Change framework to develop a software that maps out causal relations between projects' actions and potential effects, or outcomes. The development of this software is dedicated to practitioners and project proponents in sustainability science and related subjects who want to reflect on the assembly of the machinery of a particular project or projects. This article is structured as follows: In Section 2 we present conceptual elements that inform our approach; Section 3 describes our methodological approach for designing, developing and testing the software; and Section 4 and 5 present and discuss the results and lessons learned; finally, we conclude the paper in Section 6.

2 From Theory of Change to causation networks

Theory of Change (ToC) is a framework or model originated as a theory-based approach to assess the impact of social programs (Oberlack et al., 2019). ToC are mental representations and theoretical assumptions that explain how and why the activities of an initiative (project, program, organization) generate particular changes (Mason and Barnes, 2007). Approaches such as "*planning theory*" used to address social policy problems (Rittel and Webber, 1973) and "*theory-based evaluation*" (Weiss, 1997; Chen, 2015) formed the theoretical foundations for the ToC approach. However, Carol Weiss was the first to describe the value of evaluating any theory-based program in 1972 (Maru et al., 2018).

The ToC framework, although initially applied as a planning and evaluation tool for social projects, has evolved over several decades, expanding its scope to encompass sustainability initiatives. This approach generates both *ex-ante* and *ex-post* models to anticipate outcomes or retrospectively analyze outcomes and changes (Mayne, 2015). In the context of sustainability projects, this framework has garnered significant attention and has been used to monitor and evaluate interventions, programs, and projects' processes. This heightened interest stems from the need to provide tangible evidence of impacts facilitated by the sequential nature of the process, which allows for the documentation of progress between activities and change trajectories delineation (Mayne, 2017).

Although the ToC model remains widely popular (Vogel, 2012; Mayne, 2015; Mayne, 2017; Reinholz and Andrews, 2020), its evolution has been prompted by the recognition of a fundamental weakness: its inherent linearity (Abercrombie et al., 2018). Numerous scholars point out that instead of following a linear sequence of events, ToC models can also exhibit a network-like behavior. This critical insight is extensively explored by Murphy (2021), highlighting the issue of oversimplification within traditional ToC frameworks, typically presented as linear logical constructs. Other authors, such as Alford (2017), have similarly critiqued this oversimplification, drawing attention to the limitations of conventional ToC models and advocating for the inclusion of recurrent causal loop diagrams to incorporate feedback mechanisms.

In response to the above-mentioned limitations of ToC, Systemic Theory of Change (SToC) has been proposed to allow a comprehensive representation where structures can be nested, more intricate

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arrangements can be formed, and multiple projects can interconnect. Conceived by Murphy and Jones (2020, 2021) and Aragón and Giles Macedo (2010), this approach offers a framework to navigate the interconnections and interdependencies within sustainability endeavors, facilitating a more holistic understanding of their dynamics and envisioned impacts. The essence of this approach is mapping the structure elicited by SToC into a complex network structure.

The science of complex networks has provided novel perspectives and analytical tools to study various kinds of systems (Sayama, 2015). In particular, network science has been a strategy for the analysis of complex systems as networks can better capture the complexity of a system and can be constructed from actual data. Complex network analysis enables the identification of recurrent causal loops, levels of dependency, feedback between nodes and other attributes of the system. Salient features of a network, such as nodes with high degrees of connectivity or high betweenness centrality, warrant further analysis to assist identifying potential deeper leverage points for promoting change (Leydesdorff, 2007; Lee et al., 2021). There are well documented examples such as the world wide web, ecological networks, or movie-actor collaboration networks in which key actors (nodes) are drivers of system-wide behavior (Albert, 2002).

Therefore, we posit that a software that incorporates certain elements of the Theory of Change framework but developed with a systemic-network approach able to assist reflecting and designing a more coherent nonlinear project rationale, while also allowing articulating several projects to elicit potential convergences and gaps, might have the potential to contribute to more meaningfully addressing urgent sustainability challenges. These conceptual elements inspired the development of the first version of a software we describe in the following section.

3 Methodological approach and co-construction process

The development of our software application was grounded in principles of the Theory of Change framework, and integrating foundational elements of causal networks. The ultimate aim of this software was to enhance the interconnectivity of sustainability projects by embracing a more systemic and complex perspective.

The overall process consisted of three phases: 1) development of software prototype; 2) participatory spaces, and 3) software piloting. We describe these phases in the following subsections.

3.1 Co-construction of software prototype

The initial phase, carried out during 2022, involved coding the software. We selected the framework described by Mayne (2015) to serve as the basis for our code. In 2023, we continued to refine and expand the software.

We designed a data model inspired by the directed graphs used to visualize causality in ToC. In this model a list of triads of state-connection-state-also known as an edgelist-represent change. It corresponds to the "if-then-because" logic of ToC. Figure 1 shows an entity-relationship diagram of our data model.

Elements of the project identified as states are nodes. We defined them using nouns such as "an information system," "empowered communities," "public policy," etc. They can be tagged by type (social, biophysical, infrastructure, etc.) and can be located temporally and/or spatially. Nodes can be used to define initial states which correspond to problem statements or serve to define short, medium or long-term goals. Furthermore, they can describe shared objectives beyond project boundaries meaning that project designers and implementers are able to connect states outside the scope of their project activities, which could also be addressed. In this way, projects can be represented in a larger network of understanding.

Connections, also known as edges, represent causation that leads one state into another. They can stand for activities or simply pose causal relationships among states. Connections can include spatial data and temporal types (i.e., short, mid, long-term). Once nodes and edges are input to the software application, they become a useful computer model. They can be displayed as a network or exported in GraphML format for further analysis and visualization in other programs. Directed networks can be created from a subset of a project's edgelist, or from a set that includes more than one project.

3.2 Participatory spaces

A fundamental element of our approach involved engaging with groups of individuals that were implementing sustainability projects (independently of their initial or more mature stages) to both reflect on its progress and to facilitate interactions to test it. Thus, and having identified a window of opportunity that emerged from an ongoing project collaboration between our team and the Mexico City Secretariat of Education, Science, Technology and Innovation (SECTEI for its Spanish acronym *Secretaría de Educación, Ciencia, Tecnología e Innovación de la Ciudad de México*) that funds sustainability projects within Mexico City, we approached four project teams and invited them to be part of a series of participatory spaces designed to test and reflect on the software architecture and potential functions. We received a positive response from the four projects' teams. The titles and main objective of each project were the following: 1) Agroecosystems design for sustainable food production— aimed at fostering local agricultural production to reduce impacts on conservation land; 2) Agroecological sustainability laboratory—aimed at developing innovative collaborative networks that enable agroecology for different purposes related to health, food, social inclusion and education; 3) *Chinampera* school—aimed at rehabilitating an agro-food system in the *chinampas* of the Xochimilco urban wetland; and, 4) Laboratory for sustainable soil management and compost evaluation—aimed at improving soil quality through better quality compost and the substitution of chemical fertilizers. All four projects were part of the Food Safety Laboratories Network (LABSA for its Spanish acronym *Red de Laboratorios en Seguridad Alimentaria*).

Once we had these four projects on-board, and with the developed conceptual prototype for the software architecture, we embarked on a process to collectively reflect on the prototype and receive feedback to further develop the software using the four projects. The participatory spaces were designed to engage with the projects' coordinators and teams to gain insights into their project objectives, outcomes, and goals. The process consisted of two stages:

S0—First approach: a comprehensive questionnaire was designed to collect information about the projects and how they were

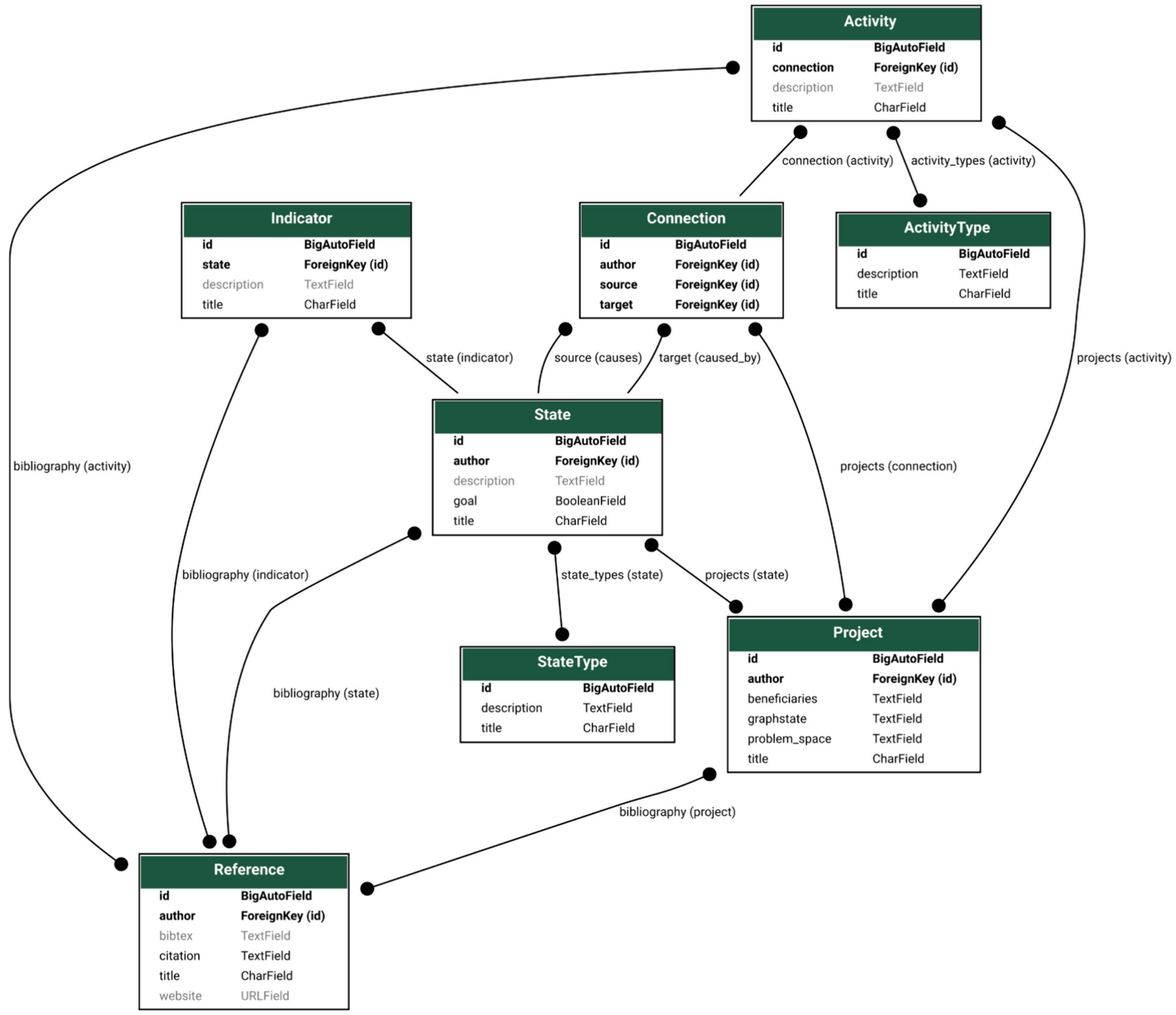

FIGURE 1
Entity-relationship diagram of our data model. Boxes represent tables and the lists they contain describe their columns. Lines represent relationships in the data.

connected to SECTEI main goal. This questionnaire was sent to the projects' coordinators, and consisted of three sections: 1) information and context about the project, 2) information about the contribution of their project to the "*Suelo de Conservación*" (conservation land policy) of Mexico City, and 3) information about the importance of belonging to the LABSA network. A total of fifteen questions served to understand the projects and this information also helped to prepare the following workshops held in May 2023.

S1—construction of the Theory of Change per project: two workshops were held in May 2023 with representatives from four LABSA's projects. The workshops aimed to co-construct each project's ToC. Guided by a facilitator, each project's team/coordinator indicated the overall goal(s) of their project and reflected on the following questions: a) What changes should occur in the system to achieve the project's goal(s)?; b) Where, and what kind of changes must occur considering the following categories: social networks, landscape and biophysical changes, governance systems, behavioral changes and new capabilities?; and, c) Which of these changes might contribute to SECTEI general goal?

The next step was to write down these changes on cards according to the following categories: a) social relations; b) landscape/biophysical; c) governance systems; d) behavioral changes or new capacities (see Figure 2). Categories are based on Meadows (2015) and O'Brien (2018) work. The categories are more profound concepts to trigger changes discussed in the above-mentioned research. They can leverage the social, environmental or economic systems mainly analyzed in sustainability projects. The intention is to reflect on aspects that could generate paradigm shifts more systemically. These cards were arranged along a timeline where T1 corresponded to the present, T2 and T3 the mid-term, T4 and T5 to the long term where the SECTEI's goal was located. Once the cards/changes were positioned along the timeline, the project's team/coordinators were asked to connect them using arrows to form a causal sequence. The scale of each change (local–L, regional–R, or statewide–S) was also indicated when identified.

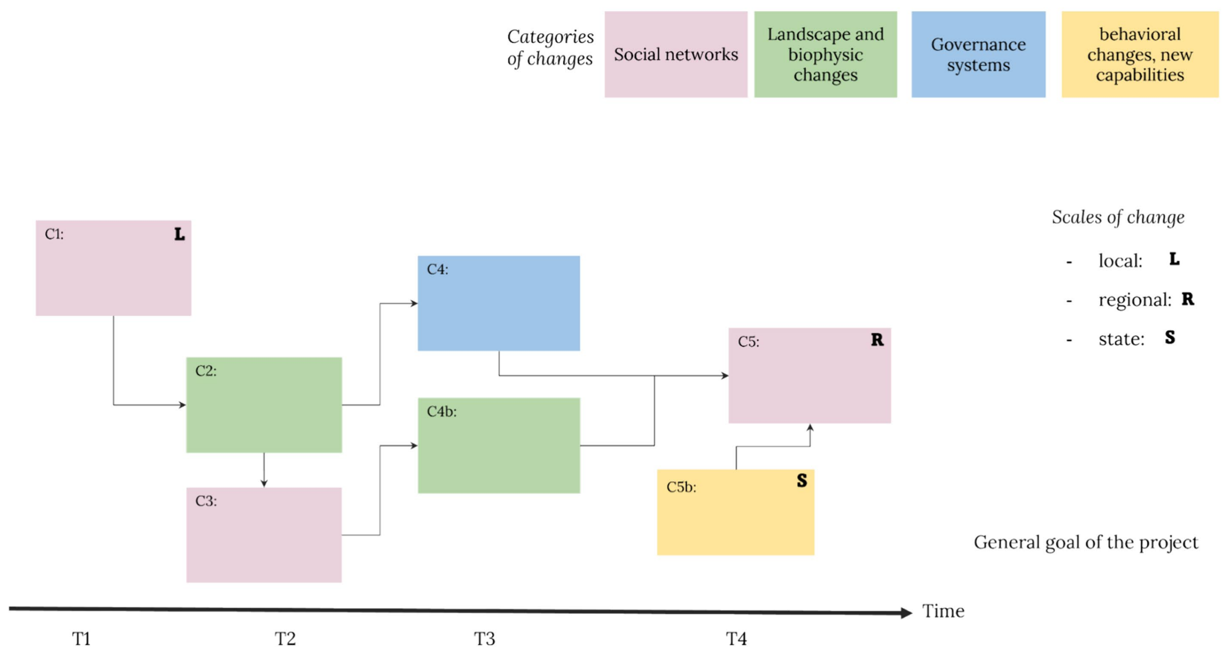

FIGURE 2
Theory of Change process. A Theory of Change was constructed for each project. A timeline with four points was used (T1, T2, T3, and T4), where the long-term institutional goal of SECTEI was captured at the end of the line. Each project builds its ToC starting in retrospect, from the project's general goal reflecting on the needed changes to achieve the goal. The four categories of change (C) were: a) social relations in pink; b) landscape/biophysical in green; c) governance systems in blue; d) behavioral changes or new capacities in yellow. Also, the scales of the changes were marked when identified.

3.3 Piloting our software application

Drawing from the rich reflections that emerged in the participatory spaces with the LABSA network group, we piloted the software using real data from the four projects by generating causal networks for each project. Afterwards, data was curated, standardizing titles' states that were similar among the projects. This step was crucial when constructing the meta-network that included the four projects. In that way, it was possible to identify the states in which different projects could find a synergy.

The development of the software is open to collaboration through a public repository hosted at https://codeberg.org/LANCIS-UNAM/prisma/.

4 Insights from piloting the software

After the interaction with the LABSA network, four networks were generated, one per project (see Figure 3A as an example of a co-produced Theory of Change network; the other three can be found in the Supplementary material). During the two workshops, participants discussed their ideas and scopes of the project's main goal, and labels were generated consensually. The space allowed the co-creation of changes that participants recognized they had not thought of individually. The temporality helped to arrange the cards and activities developed within the project. The creation of a collaborative change network yielded reflections that the members had not considered before working as a group, even though the projects were already underway (for example in the Chinampera School project, they visualized the amount of work needed to have the percentage of Chinampas implemented to achieve their goal).

The model that was generated in the workshops shows the first stages of the Theory of Change methodology in which the different states were arranged over time until the desired goal was reached by project and then by institutional goal. Once the cards were curated, these were entered into the software. We then obtained networks with shorter names that homologated the desired states among the four projects and were linked by the activities that make the states change over time. Here we present the example of one network (see the Supplementary material for the other three networks). Finally, using the network merging functionality of our software, we show the meta-network of the four networks where we observe two converging points between the projects that were added using the software. We found that each project addresses different themes and issues that are not necessarily connected but can all be aligned with the overall goal of SECTEI.

States, connections and activities from the workshops were input to the platform thereby populating three relational tables: states, connections, and activities. The corresponding data was read directly in those tables or visualized within the platform using an interactive graphical interface. Visualization is a part of the analysis of complex networks, but the most important feature is that they are computer models that can be further analyzed by mathematical and computational techniques in fields of knowledge such as topology and complex network theory. By storing the complex networks in a relational database, detailed queries can be made for any search criteria. Search results are interpreted as edgelists from which subnetworks or super-networks are created. This means networks can

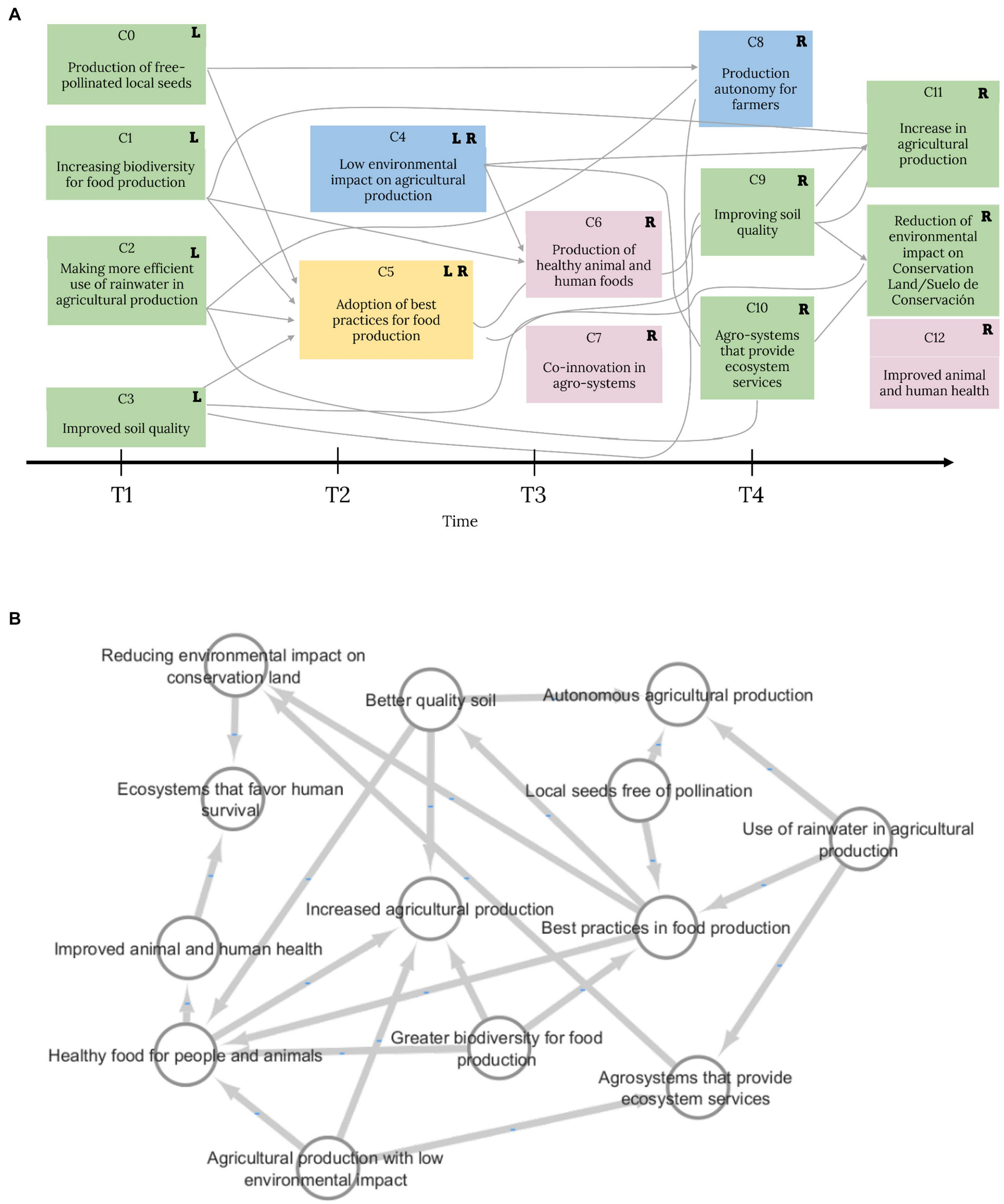

FIGURE 3
(A) Theory of Change network co-produced with project coordinators. This figure is the Agroecosystems design for sustainable food production project network that identifies the changes needed to achieve the network-wide goal based on the activities they carry out. The colored cards show changes on a) social relations in pink; b) landscape/biophysical in green; c) governance systems in blue; d) behavioral changes or new capacities in yellow. **(B)** An adapted Theory of Change model is shown from the same project.

be created from only parts of projects or from more than one project at a time or even the whole database. This ability to split or merge allows for powerful flexibility. Additionally, a subset or superset can be exported in GraphML format, which allows for further analysis using external specialized software such as Cytoscape, Gephi, NetworkX and many more.

By using the software, we obtained a meta-graph that linked all the projects of the LABSA network. This allowed us to identify two

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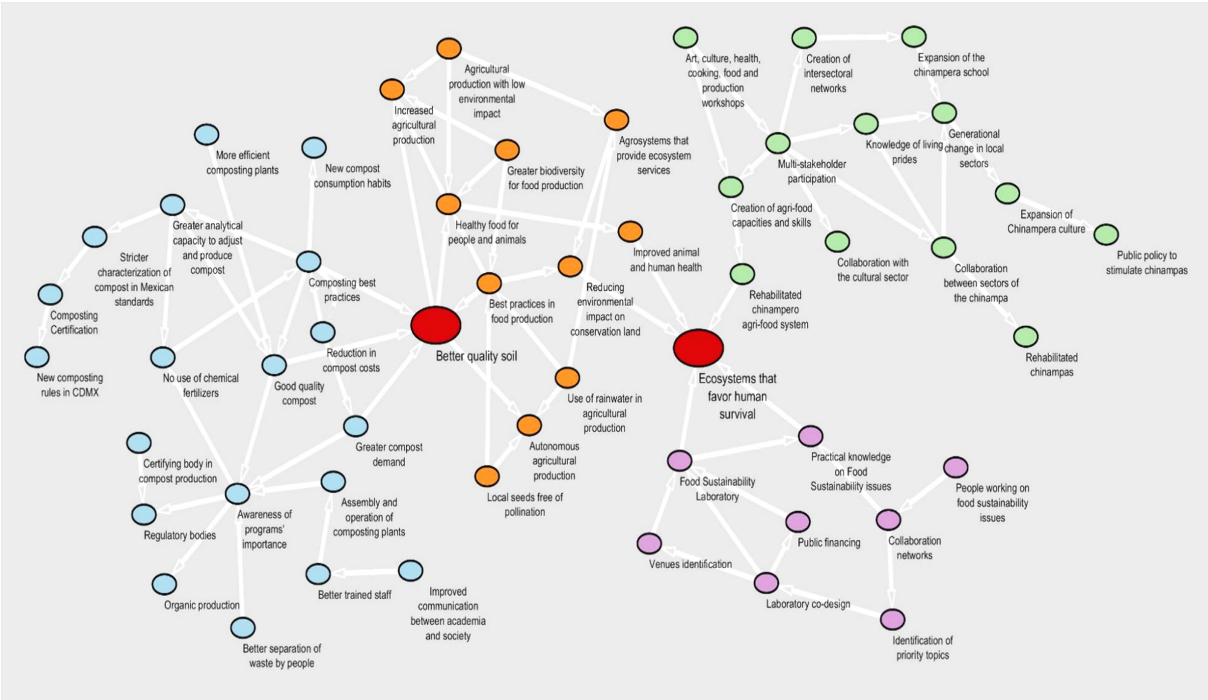

FIGURE 4
Metha graph showing the four LABSA network projects and the nodes where these converge in red (developed with Cytoscape-version 3.10.0.). We observe the a) Chinampera School in green, b) Laboratory of Sustainable Soil Management and Compost Evaluation Project (LAMSSEC) in blue, c) Agroecological Sustainability Laboratory (LASOS) in purple, and d) Agroecosystems design for sustainable food production in orange.

shared nodes (better quality soil, and ecosystems that favor human survival). Figure 4 shows the distribution of the states of each project and the concurrent states among the four projects. These were better quality soil and ecosystems that favor human survival.

5 Discussing lessons learned

As explained, the development of the software was informed from the outcomes of the participatory workshops where participants crafted networks for their projects based on elements from the Theory of Change approach. Through these participatory spaces, participants collectively envisioned a joint trajectory towards common objectives while discussing both anticipated challenges and potential opportunities. This inclusive approach not only allowed identifying overlooked aspects crucial for achieving shared goals, but also fostered an atmosphere of transparency and collaboration. Moreover, using our software in these spaces facilitated the identification of interconnected states of change across projects that would enable participants to forge more meaningful connections and pool resources effectively. Hereafter, we discuss five main lessons learned through the first phase of the software implementation.

5.1 Resisting a dominant linear logic

As we are all generally programmed to represent projects' processes in a linear sequence, conventional dominant approaches perpetuate simplistic models or frameworks such as the Logical Model, or even the ToC, and thus determine the toolsets and indicators to evaluate the projects' outcomes and impact. These tools and approaches are designed to deal with complexity by simplification. Although mapping objectives and activities along a single trajectory expresses expectations in a clear way, it lacks the possibility to emphasize other important connections among states, where chronological order is irrelevant (but doable if necessary). During the workshops we observed participants initially expecting a tool for planning, but not for reflection. This became apparent in how several participants immediately looked for ways of chronologically ordering objectives and activities.

When organizing nodes by chronological succession, time is a straight line, but causation connectors are heavily warped and difficult to follow (Figure 3). However, when organizing nodes by proximity for their visualization, loops are readily apparent, although time is no longer a straight line (Figure 3B).

However, although we acknowledge the need for timelines in project planning, by their nature they emphasize linearity and, in a way, obfuscate complexity in causation, (as stated by Abercrombie et al., 2018 and Murphy, 2021). By contrast, modeling projects as complex networks might tackle these limitations (Murphy, 2021). If a causal network is arranged by proximity of states, connections are simple lines and phenomena such as circular causation are clearly represented as loops in the network. Thus, the software allows the creation of these connections meant to express circular causation. Although states in our software can include expected dates, creating networks with our software is about causality connections. Networks of causation are inspired by ToC, but by explicitly representing them as complex networks might contribute to embracing the complexity of wicked problems in the very way we analyze them and plan actions that might contribute to tackle them.

5.2 Balancing opposing cyber-human uses

We anticipated two different use patterns of our software: 1) in workshops, with facilitation, and 2) by lone self-motivated users operating without facilitation. Thus, our software was designed to assist both uses.

Regarding the first use, the meta-graph showed to be more useful when states and connections are clear descriptions of consensual reality. However, consensus is often difficult to achieve (e.g., it is common to have different names for the same things or use the same names for different things). Therefore, facilitation is instrumental for achieving agreements on a homogeneous use of the relevant terminology. Thus, states, connections, and activities can be more clearly identified by users from different teams and organizations. A further advantage is that facilitators can elicit knowledge in depth from disciplinary scientists or field experts who may not be familiar with ToC or complex networks. However, facilitating interactions also presents challenges, such as the logistics of organizing in-person or virtual workshops that involve convening actors at the same time (Tarmizi et al., 2006).

Regarding the second use pattern pertaining to lone self-motivated users, operating without facilitation may be easier to achieve as there is no imperative to organize workshops where all participants are present. We are inspired by examples of mass collaboration such as Wikipedia, whose essence is to allow immediate edits by any reader, thus allowing a collective curation of the content. Therefore, our platform should also be available to a wide audience and enable a broader coverage of the problem space, although missing the depth and clarity achieved through facilitated collective analysis. However, even if users' engagement might be superficial in contrast to facilitated dialogue processes, aggregated participation of many users may contribute to creating more plural understandings by generating valuable data sets for collective decision making (Hamada et al., 2020).

Our design contemplates concurrent editing of all the objects that conform to causal networks. Like in wikis, there should be no need for authorization before changes can be made, instead a log of every change should be preserved, and means should be provided for restoring objects to any previous state. This model for mass concurrency is commonplace in tools such as Git (Chacon and Straub, 2014) where several web-based platforms for collaboration have been developed (e.g., Gitea, Forgejo). As such, our network design contemplates visualizing additions in green, deletions in red, and the rest in neutral colors; and a closer inspection of edited texts should use a normal diff-patch display (MacKenzie et al., 2002). With this design, different structures of causation can be developed and used for fostering discussion among users, which is useful even if no consensus is reached.

5.3 Closing gaps and finding synergies by the creation of a meta-graph

Integrating all elicited projects' causal networks yielded a sparse meta-graph in which each project was a subnetwork disconnected from the others. Further analysis enabled us to connect them all into a complete graph by adding two states that represent ultimate goals (as shown in Figure 4). Although the only means to connect projects was by including such nodes, it could also be the case that sub-graphs can be connected by renaming some of their states in such a way that they describe the same issue and thus can be fused. As fusing nodes can be assisted by facilitators, our design entailed a toolset for contrasting different possible structures, as described in the previous section.

Hence, we expect the platform to be useful in negotiations necessary for different teams to agree on naming and describing shared states. Furthermore, other tools might be developed for mobilizing computer power in the detection and suggestion of similar concepts (such as Natural Language Processing or Large Language Models; Bates 1995).

We expect future workshops supported by the completed software version to yield connected networks in which intermediate nodes shared by different projects will be described as such by participants. We believe that finding common ground about these nodes could detonate unexpected collaborations and serve as a basis for designing transdisciplinary strategies.

5.4 Making connections without activities

In the participatory workshops, we observed some participants that placed their projects in a wider context, which was described by states causally connected to objectives in their projects, but for which no activities were planned. For example, long-term objectives were commonly added and connected, but activities were only placed and described as connections between states within the project. Nevertheless, we found that states within and beyond the project are valuable descriptions of particular contexts, problem spaces, and stated goals. Therefore, our design enabled including connections between states that may or may not contain activities, as connections are meant to express causation without regard to intervention.

5.5 Strengths, limitations, and next steps

Using tools and workshops to model change collaboratively and ideally in a transdisciplinary environment is advantageous because it fosters reflexivity. As described by Giddens (1976), reflexivity involves the acknowledgement that the subject influences the object through self-awareness or self-reflection. This brings stakeholders to critically examine their assumptions, biases, and worldviews, fostering a more holistic understanding of the complex interconnections between social, economic, and environmental factors. Reflexivity allows project teams to continuously monitor and adapt to changing circumstances, ensuring that interventions remain relevant and effective over time (Gurtner et al., 2007). Also, reflexivity encourages creativity and innovation by challenging conventional thinking and exploring alternative approaches to sustainability challenges. By embracing diverse perspectives and knowledge systems, projects can generate novel solutions that may not have been apparent within traditional disciplinary boundaries (Lang et al., 2012). This participatory approach not only enhances the legitimacy and acceptance of sustainable initiatives but also builds capacity within communities to address future challenges independently. Thus, fostering reflexivity is a substantial strength of our software.

On the other hand, a weakness of our software is that users presented with a network tend to interpret connections as chronological order. Perhaps this is due to similarities with widespread project management tools such as the "Critical Path Method (CPM)"

(Kelley and Walker, 1959), or the "Program Evaluation and Review Technique (PERT)" (Fulkerson, 1962). These tools make use of networks with an emphasis on the scheduling of tasks. Our software is not meant for project management, yet it was frequently perceived as such since it asks about project objectives and activities.

Furthermore, although developing complex networks can be a challenging endeavor, creating a network with the graphical user interface in our program is relatively simple. Workshops' participants and collaborators alike seemed tempted to use visualization as the only means for analysis. The next versions of our software should consider adding other analytical tools that include different visualizations not only of the networks themselves, but of their most important metrics. Adding brief and precise explanatory texts could also help to better understand the tool, as well as serving educational purposes. Nevertheless, the use of complex networks as computational models of causation may be a strength if it helps transdisciplinary scientists to integrate large numbers of projects to create holistic narratives.

As stated, the development of this software is a work in progress. We plan to have other series of workshops and iterative trials to improve the user interface by allowing better interactions among different users. We also plan to develop a way of onboarding lone users in such a way that noise is kept to a minimum and the collective meta-graph makes the most sense to all participants. Ultimately, we aim to engage a wide and diverse group of users that could find our tool useful for their endeavors.

6 Conclusion

In this work we presented the initial steps of a project in which we developed a software aimed at creating a meta-graph tool as a virtual nexus where myriad projects intertwine to enable a cyber-human space to facilitate reflecting on projects' architecture and planned outcomes. Through adapting elements of the Theory of Change model, this software was used to guide participants in designing causation networks that transcend the dominant linear project logic and allowed them to unveil the articulation of different projects to then identify common elements. Thus, we posit that this tool could be instrumental in fostering new possibilities for coordination and synergy among initiatives, and in promoting reflection when crafting projects that aim to more meaningfully address sustainability problems.

Particularly from the participatory spaces we learned that by curating the states of the theories of change of the LABSA network projects we were able to connect them with concurrent goals and objectives. This interaction was *a posteriori* and there were few overlapping nodes. As ongoing projects, activities were already implemented and there was no space for a change. They recognized that using ToC allowed them to visualize more connections among states within projects. This approach was of particular interest to SECTEI and the LABSA network as a means to understand if the projects are linked and how.

Finally, our approach showed the importance of reflexivity as a transdisciplinary strategy to advocate for more meaningful changes through widening breadth, deepening understandings, and collectivizing analyses within a creative space designed to visualize and analyze causality, complexity and connectivity among projects. By recognizing similarities and potential convergences among efforts, social actors might contribute to amplify the impact potential of initiatives aimed at addressing complex sustainability challenges. We hope this effort inspires others to create mechanisms and conditions to collectively imagine transformative changes towards more plural and shared sustainabilities.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Author contributions

PG-M: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. RG-H: Conceptualization, Methodology, Software, Visualization, Writing – original draft. FS-C: Conceptualization, Formal analysis, Methodology, Software, Visualization, Writing – original draft. LC-J: Writing – review & editing, Conceptualization, Writing – original draft. JM-N: Investigation, Methodology, Writing – review & editing, Data curation, Formal analysis, Visualization, Writing – original draft. JM: Investigation, Writing – review & editing, Methodology. EP-V: Methodology, Writing – review & editing, Formal analysis. SG-A: Investigation, Writing – review & editing, Data curation, Formal analysis. AF-R: Writing – review & editing, Conceptualization, Investigation. AT: Methodology, Writing – review & editing, Software, Visualization. JC-J: Investigation, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsus.2024.1405501/full#supplementary-material

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