Transdisciplinary Research in the Built Environment: A Question of Time

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Paula Femenías and Liane Thuvander

> *"We had the technical part ready but realized that this was the simple part of the challenge."*
>
> Industry partner in project ReBo,
> a transdisciplinary research project described in this study

In this article, we reflect on 14 years of experience with transdisciplinary research in the built environment. We critically consider challenges and pitfalls in relation to normative definitions of transdisciplinary research derived from the literature. Our experiences from five transdisciplinary research projects are presented with a focus on each project's aim, size, organization of work, and funding. Results show that different kinds of transdisciplinary research approaches co-exist and that these can serve different purposes and situations. In most cases, transdisciplinary projects lead to raised levels of awareness of the complexity of real-world problems among participating partners. In some cases, the outcome is a useful innovation, in order to support such innovation, a focus on real cases is encouraged. However, there might be a trade-off between the focused attention on a real case and the maintained interest among diverse participants in a larger project. An important insight is that innovation and knowledge development through transdisciplinary settings take time. It is favourable for the development of networks, common visions, trust, and innovation if consecutive transdisciplinary projects can be arranged with the same partners. We conclude the article by providing practical guidelines to support the management of transdisciplinary projects.

Introduction

Transdisciplinary research approaches have been brought forward as a means to solve and mitigate real-world problems where disciplinary and interdisciplinary research approaches fall short. Transdisciplinary research or "Mode 2" knowledge production, in contrast to traditional disciplinary "Mode 1" research, brings together researchers from different disciplines with non-academic stakeholders from industry, the public sector, and civil society in order to address and develop applicable solutions to societal problems (Brandt et al., 2013; Gibbons et al., 1994; Lang et al., 2012; Spangenberg, 2011). Key benefits of this new paradigm are that it transcends disciplinary boundaries and brings in knowledge from various communities of knowledge –including from outside academia. Transdisciplinary research also goes beyond problem analysis in search for efficient guidance, strategies, and innovation. Through collaboration with stakeholders, legitimacy and ownership are created, which in turn build potential for the up-take of innovation.

Transdisciplinary approaches have been found especially relevant in the field of sustainability science as it is normative and problem-solving oriented (Lang et al., 2012). With its lack of innovative power, transdisciplinary approaches also have particular relevance for the built environment (Sexton & Lu, 2009). The complex nature of the building industry makes it essential for the research community to engage with stakeholders as a means to reach higher degrees of applicability, for example in relation to innovation for energy efficient technologies (Berker & Bharathi, 2012; Oreszczyn & Lowe, 2009). In addition, in Sweden, research funding agencies increasingly emphasize academia–industry collaboration by requiring participation and co-funding from non-academic stakeholders on topics related to sustainable development of the built environment. This co-funding can reach up to 50 % of the project budget in order to be legitimate and can be in-kind or ready assets.

In this article, we reflect on our practical experiences when engaging in transdisciplinary research in the

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built environment with the aim to contribute to the development of practical guidance for the management of this kind of knowledge development and innovation.

Our approach is qualitative and the method is identified as reflexive retrospective (Mitev & Venters, 2009). A reflexive approach deviates from traditional post-hoc accounts in which the success of pre-defined objectives and deliverables are assessed by attempting to capture the experiences of the researchers and the non-academic partners. We broadly follow Alvesson and Sköldberg's (2009) four levels of reflective interpretation, as further developed by Mitev and Venters (2009). The four levels include reflective interpretation of:

1. The empirical material.

2. The project partners' perspectives in relation to the empirical material.

3. The empirical material in relation to the earlier accounts of transdisciplinary research.

4. Our own personal relationship to the studied object.

Although we have experiences from about 15 transdisciplinary research projects spanning a period of 14 years, here we focus on five projects – Demo04/06, 3iii, ReBo, SIRen, and STED – that are summarized in Table 1. The projects vary in size, in terms of participants and budget, and in organization of work, but they also represent a continuous line of investigation through consecutive projects.

The reflexive retrospective approach draws on the analysis of empirical material from the projects (e.g., observations, presentations, meeting notes, reports, publications, and other project documentation), which have been interpreted along with memories of the authors. In addition, in the projects Demo04/06 and 3iii, interviews were made with all participants during the course of projects to capture expectations and experiences, and in the case of ReBo and SIRen (Table 1), post-project surveys among all participants. The reflection itself was made through discussions between the authors, by writing this article, by responding to the editors' and a reviewer's suggestions, and by interpreting the experiences and visualizing them in figures.

The article is structured as follows. The first two sections briefly summarize definitions and challenges for transdisciplinary research found in the literature. After that, results as well as our reflections from five transdisciplinary projects are presented. The presentation follows the same structure for each project describing their aim and approach, innovation and learnings produced, and outcomes. Next, we discuss our reflections in relation to earlier experiences of transdisciplinary research. Finally, we conclude by presenting a number of guidelines for the management of transdisciplinary research projects.

What is Transdisciplinary Research?

Lang and co-authors (2012) argue that it is not possible to give a recipe or general definition of transdisciplinary research as it is in the nature of these projects to be embedded in specific contexts. Indeed, the case-specificity makes it difficult to generalize practical experiences (Bresnen & Burrell, 2013; Lang et al., 2012). Nevertheless, the literature in the field does identify some commonalities.

Gibbons and colleagues (1994) formulated the original and well-cited thesis for what they called "Mode 2" as a complementary and new way for knowledge production to deal with problems that could not be circumscribed by a single existing disciplinary field. According to them, Mode 2 knowledge production is characterized by five attributes:

1. Producing knowledge in a context of application. The context-specific and problem-solving nature of Mode 2 is organized to meet needs of a particular social setting as opposed to norms and rules of a particular discipline. The project should be responsive to the emergent situation.

2. Transdisciplinary, demanding real-world problem settings and integration of different disciplines and skills.

3. Heterogeneous and organizationally diverse. The real-world problem requires transient teams whose membership changes to respond appropriately to the emergent situation.

4. Socially accountable and reflexive. The participants need to be sensitive to the actual and perceived impacts of their activity by interests outside the action group necessitating a deeper appreciation of the research process itself on the part of the participants.

5. Diverse quality controls that reflect the concerns of a broader community of interest.

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Based on a review of a larger number of transdisciplinary research projects, Lang and co-authors (2012) describe three phases that such projects follow. In the first phase, the collaborative team is set up and together they develop an understanding of the problem and decide upon models for working. It is essential in this phase that the real-world problem is translated into a boundary object, meaning an object or a concept that serves as an interface between the boundaries of different disciplines, organizations, and cultural communities. A boundary object has been described as socially enacted and open for interpretation and negotiation (Styhre & Gluch, 2010). It should be fluid enough to bridge various communities while at the same time robust enough to maintain a common identity across sites (McGreavy et al., 2013). Another key aspect in the first phase is to develop a "common language" among participants. In the second phase, the research is coproduced. Finally, in the third stage, knowledge should be re-integrated and applied both in scientific and societal practice. Lang and co-authors (2012) emphasize that the produced knowledge can be tools or enhanced processes but can also be more indirect results such as learnings and new perspectives.

Even if there are many commonalities and a consensus about the main features of transdisciplinary research, there is still a disagreement about their reciprocal importance. Transdisciplinary research has been criticized for reinforcing the loss of academic autonomy and adding to the subordination of academic science to market forces (Grey, 2001). Balsiger (2004) questions the real scientific need for transdisciplinary research and argues that it is more a principle than a scientific approach. Shinn (2002) describes transdisciplinary research to be more of a social platform than a scientific methodology. Leydesdorff and Etzkowitz (1998) argue that the increasing academy–practice collaboration is not so much a result of a transition towards Mode 2 research but a cause for this development, as society is characterized by a "disorganization" of institutional barriers.

Several authors argue that there is no clear distinction between Mode 1 and Mode 2 research and they instead mostly overlap (Bresnen & Burrell, 2013; Ziman, 1996). Pohl and colleagues (2010) state that transdisciplinary research does not have to be participatory (Pohl, 2011). Elzinga (2008) says that the degree of participation depends on the goal of the project. What is important is to reach valuable knowledge that grasps the complexity, takes into account diverse perspectives, links the abstract and the case specific, and develops both descriptive and practical knowledge for the "common good" (Pohl, 2011). Spangenberg (2011) suggests a distinction between science *for* sustainability (rather monodisciplinary) and science *of* sustainability (interdisciplinary and transdisciplinary).

A controversy is apparent with respect to descriptive and practical knowledge in transdisciplinary research, also called "knowledge first" or "process-orientation" (Miller, 2013; Wittmayer & Schäpke, 2014), and whether the scientist should take a role as "descriptive analyst" or "transformational activist" (Wiek et al., 2012). The process-orientation approach emphasizes relevance and actionable knowledge, defined as knowledge that can "change professional practice or social institutions through active and transformative participation of those working within a particular setting" (Crawford, 1995). The creation of an arena (Eden et al., 2005; Falkheden & Malbert, 2004; Loorbach, 2007; (Pohl et al., 2010) is a core activity in process-oriented projects, to host meetings, discussions, and reflections to support social learning. Such arenas have been described as a protected space (Loorbach, 2007) or a neutral space where participants can meet on an equal footing, beyond the constraints of roles, power dynamics, and limitations of specific projects (Falkheden & Malbert, 2004). Transdisciplinary projects should benefit from a non-hierarchical approach to knowledge production (Balsiger, 2004). These social platforms and protected spaces need to be maintained during the course of the projects (Wittmayer & Schäpke, 2014), and regular meetings should be held on an ongoing basis to support the interest in the group (Deprés et al., 2004).

Challenges of Transdisciplinary Research

Reported practical insights from working with transdisciplinary projects show that the transition from Mode 1 to Mode 2, and on to more collaborative science, is not effortless. Conflicts have been observed in projects where the expertise of institutions has been devalued and where existing hierarchies have been challenged (Berker & Bharathi, 2012). Interdisciplinary meetings can lead to conflicts about ontologies and methodologies, while the transdisciplinary approach in itself can be problematic in terms of producing legitimate results that are acknowledged as reliable and valid (Lang et al., 2012; Wiek et al., 2012). Suspicion that academic knowledge is inadequate for use in practice might also be prevailing (Argument et al., 1998). Furthermore, joint knowledge production can suffer from confounded

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agendas, reluctance to face exposure, and varying value preferences (Wiek et al., 2012). Lang and co-authors (2012) and Wittmayer and Schäpke (2014) describe challenges with unbalanced ownership of problems, insufficient legitimacy of the team or the actors involved, and the fear of failure. There can also be a mismatch between academics wishing to offer solutions that will be implemented in the long term and companies seeking to implement short-term solutions to the problems they are experiencing today (Argument et al., 1998; Falkheden & Malbert, 2004). Also, some academics have experienced proprietary control of results on the behalf of participating companies, something that will inhibit open knowledge development and diffusion (Lang et al., 2012; Mitev & Venters, 2009).

While benefiting from an accuracy of research topic and broader interest in results, transdisciplinary research also puts strain on the research process, on workload, and the possibilities for achieving scientific credits (Berker & Bharathi, 2012; Lang et al., 2012). The management of the project can be a puzzle. The researchers will find themselves in new roles for which they are not appropriately trained (Wittmayer & Schäpke, 2014). They will need to deal with tensions that can arise between participants and assume a role of knowledge broker or facilitator. These new roles need time and resources to develop skills. Wittmayer and Schäpke (2014) argue that "institutional space" is needed from the universities and from funding agencies to support researchers in their production of scientific publications as well as their handling of processes to improve the societal relevance of results. Lack of time and resources for organizations to engage in the transdisciplinary projects can hinder the co-production of knowledge, but also individual's (non-)willingness to adapt and share knowledge (Gluch et al., 2013). Another inhibiting factor is discontinuous participation among staff of collaborating companies and organizations change workplace (Lang et al., 2012). In their study of an arena in the built environment, Gluch, Johansson, and Räisänen (2013) found that the motivation to share knowledge is related to each individual participant's expectation of, and invested interest in, arena activities.

Experiences from Five Projects

Five cases of transdisciplinary research illustrate practical experiences with this form of research. The selection reflects differences in size, funding, and approach of the projects (Table 1). At the same time, they demonstrate a chronological development of working with transdisciplinary research through consecutive projects.

Demo 04/06 – Demonstration Projects for Sustainable Building

Aim and approach: These first two transdisciplinary projects followed a tradition of engaging in action research in the Department of Architecture at Chalmers University of Technology in Gothenburg, Sweden. They were motivated by an observed gap of innovation from demonstration projects to mainstream sustainable building (Femenías, 2004). The objective for Demo 04/06 was to further understand but also support innovation in sustainable building by sustaining a knowledge-sharing arena around six ongoing frontline demonstration projects for sustainable building (Rubino, 2006). Developers, architects, and technical consultants engaged in these projects met 3 to 4 times a year to discuss problems and experiences. The explorative arena was designed and led by the researchers. At times, the arena was opened up to external participants. Connected to the arena, there were change agents, actors, and organizations identified as possible agents to diffuse knowledge outside the arena.

Learnings and innovation: The arena was appreciated and well-attended by collaborating as well as external companies. Sustainable building was still in its infancy, and practical experiences and built examples earned much attention. However, the good results from the demonstration projects were not diffused and, even more important, they were seldom taken up by the organizations that were involved in them. Demonstration projects continued to be one-off investments without any larger impact on the industry. The project analyzed a number of inhibiting factors based on socio-technical transformation theory (Rubino, 2009).

The legacy of these first projects is the building of trust and relations with a local network of industry partners. This has been an important foundation for new collaborations and transdisciplinary projects.

Outcomes: The project led to a PhD thesis (Rubino 2009) and to a number of other scientific papers (Eden et al., 2005; Femenías, 2005; Femenías et al., 2008). The projects also resulted in a guidebook, which was a kind of hypothesis for an improved innovation process among construction clients (Femenías, 2009).

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Table 1. Information about the five transdisciplinary research projects carried out from 2004–2018

Project	Aim	Size	Budget
Demo 04/06 2004–2009	Understand and support knowledge transfer between demonstration projects	Medium 20–30 participants evolving around 6 case projects: 1 academic institution and 1 academic discipline; 15 public and private organizations	Phase 1 (04): 1.10M SEK (~$160K CAD) research funding Phase 2 (06): 3.17M SEK (~$450K CAD) research funding
3iii 2009–2013	Understand and support innovation processes in client organizations	Small 8–10 participants: 1 academic institution with 2 academic disciplines; 1 national public client organizations; 2 municipal client organizations	2.20M SEK (~$315K CAD) research funding 2.36M SEK (~$340K CAD) in in-kind and 600K SEK (~$85K CAD) in effective as co-finance Request: minimum of 50% co-finance of which 20% in ready money
ReBo 2010–2012	Define and support integrated sustainable renovation	Medium 20–30 participants evolving around 3 case projects: 1 academic institutions with 4 disciplines; 13 private and public organizations/companies	2.46M SEK (~$350K CAD) research funding 2.50M SEK (~$360K CAD) in-kind co-finance Request: 50% co-finance
STED 2016–2018	Develop and support uptake of digital tools for sustainable design	Medium 12–15 participants: 4 academic institutions with 2 disciplines; 5 architect offices in the Nordic Countries	1.20M NOK (~$190K CAD) research funding 1.20M NOK (~$190K CAD) in-kind co-finance Request: 50% co-finance
SIRen 2014–2018	Develop tools, share knowledge, and support innovation for sustainable integrated renovation	Large >50 participants: 10 academic institutions and 5 disciplines; 21 private and public companies and organizations	23M SEK (~$3.3M CAD) research funding 23M SEK (~$3.3M CAD) in-kind co-finance Request from funder: 50% co-finance

3iii – Initiating and Implementing Innovation for Sustainable Building

Aim and approach: As a result of the lack of innovation for sustainable building, 3iii was initiated with the specific aim to understand innovation processes in client organizations, which is a key actor to innovate for sustainable building. 3iii engaged a small number of participants, a few of whom had established connections with common interest from Demo04/06. The project and the arena were driven by the academic actors and focused mainly on description and knowledge-first. The project was encircled around project workshops and traditional descriptive studies of the organizations involved, their innovation systems, and a smaller number of sustainable building projects.

Learnings and innovation: The project experienced problems with trust between the academic institution and some of the partners. A particular challenge was that one of the collaborating partners underwent a larger re-organization during the project. Also, the employee from that organization that initially discussed the participation in the project retired before the project started. The search for replacement employees delayed the project start by almost six months. Furthermore, the new employees joined the project mainly out of obligation, and they expressed a lack of interest and almost distrust towards the aim and the leadership of the project. At that time, all municipal organizations in the city experienced internal investigations to fight corruption, which could also explain their opposition to studies of their internal processes.

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Equally, in one of the other participating organizations, some employees were rather unwilling to provide data. This could be explained by the challenge that the responsible participant had in generating interest and trust for the research projects among other employees in their organization. In later stages, a conflict arose between the researchers and the "implementation agent", a role assigned to one industry participant by the funding agency to ensure the implementation of results from the research project.

Over the course of the project, the participating client organizations did achieve some successful innovations in sustainable building. Although the motivation to adopt and implement innovations had been enhanced, new problems were detected and studied such as the gap between planned and evaluated energy efficiency.

Outcomes: The project has been presented in scientific papers (Bougrain & Femenías, 2016; Femenías et al., 2009; Femenías & Kadefors, 2011), a scholarly book chapter (Bougrain & Femenías 2017), a popular science book chapter (Kadefors & Femenías, 2012), and in a new guideline for systematic innovation in client organizations (Kadefors & Femenías, 2014). Over 300 copies of the guidelines were distributed, and the content was presented during several well-attended seminars.

ReBo – Strategies for Integrated Sustainable Renovation

Aim and approach: The aim of this project was to frame problems of sustainable renovation through development of strategies to support decision making for sustainable renovation of multi-residential buildings from the Swedish pre-boom "Folkhem" period (~1940–1960). The point of departure was to weigh environmental performance, energy efficiency, and cost-effectiveness with cultural, historical, architectural, and social values when making decisions about building renovations and alterations. A further aim was knowledge sharing.

Inspired by the arena concept, successfully developed and applied in the Demo 04/06 project, the ReBo project focused on knowledge and innovation on sustainable renovation by gathering partners from industry and the public sector (Thuvander et al., 2011) using the arena model.

Experiences: The ReBo project was mainly process-oriented and the large group of practitioners meet for discussions, workshops, and common study trips (Figure 1). Without having consulted practical literature on transdisciplinary research, which was scarce at the time, ReBo naturally followed the three steps later described by Lang and co-authors (2012). Initially, the researchers stepped back and let the arena develop a common understanding of the problem. One of the results was that participants in the arena decided after several meetings to complement the expertise in the group by inviting the Swedish tenants association to participate.

The first phase became rather long and unfocused until the group decided to centre the discussions around a few real cases of renovation, which the property owners in the group were planning for. At the same time as this was a way forward, it also split up the arena. In the second phase, work was carried out in smaller groups encircling some of the property owners and their real cases. One of these sub-projects was successful in creating a boundary object, a process matrix for integrated sustainable renovation, which made the subject more tangible for all involved (Thuvander et al., 2013).

The project met a few challenges. As in the previous projects, there was a discontinuity of participants as individual employees from participating organizations were replaced during the course of the project. The researchers also underestimated the importance of informing the new participants about the specificity of the process-oriented and non-hierarchical transdisciplinary project set-up. A new participant, for whom this kind of transdisciplinary project was unfamiliar, questioned the approach and asked the researchers to take stronger leadership of the process. This event created a bit of a confusion in the arena, and even made the researchers start to question their approach and outline for the project.

Figure 1. Workshop in the Rebo project 2011, held in a bus during a study trip

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The project also suffered from a confusion between a "real" renovation project, which engaged other consultants not involved in the research, and the parallel "shadow" (i.e., non-paid) investigations in the ReBo arena. The fuzzy delimitation between the research project and the real renovation projects also affected the innovation processes as practical and economic aspects, upheld by the property owners, ruled out even the theoretical investigation of new innovative solutions and strategies.

Learnings and innovation: The ReBo project was an eye opener for participants about the complexity of this kind of sustainable renovation, as indicated in the opening quotation of this article. However, the project also resulted in some concrete knowledge production and innovation. A process matrix developed in the later phases of the project (Thuvander et al., 2014) was later on used by the property owner that was involved in its development. However, the matrix was of less practical value for the other industry partners in the arena. The process matrix was further developed in two new transdisciplinary research projects, SIRen and STED, as described below.

Outcomes: The project resulted in scientific papers (Femenías et al., 2013; Thuvander et al., 2011; Thuvander et al., 2012; Thuvander et al., 2013), reports (Danielsson et al., 2014; Thuvander & Femenías, 2014), and a book chapter (Thuvander, 2015). Some reports, conference papers (Ottoson & Thuvander, 2013; Ottosson et al., 2014), and a popular science article (Thuvander, et al., 2014) were co-authored with industry partners. The project also held a number of public outreach seminars with good attendance.

STED – Sustainability Tools for Environmental Design

Aim and approach: The aim was to develop and support innovation of digital tools for sustainable architectural design focusing on new construction, as well as renovation and transformation. The main aims were: 1) to develop innovative generalizable system design solutions; (2) to create innovative design methods using ICT for decision support combining energy efficiency, environmental design, and lifecycle thinking; and 3) to boost knowledge creation by creating a Nordic Innovation platform. STED, the only international project presented here, involving partners from five Nordic countries, each co-funding 50% of the project costs.

The knowledge-sharing arena met twice a year, and in between, three academic partners from Denmark, Sweden, and Norway engaged in knowledge production with the five architect offices in Sweden, Norway, Denmark, Finland, and Iceland. In most cases, students were involved by working in design studios or doing a master's thesis.

Learnings and innovation: The knowledge-sharing arena had the function of a discussion group with open and vivid discussions. The participants from academia acted as knowledge mediators but also saw the richness of knowledge that exists at the offices and the challenges to integrating it. Not all of the involved architects were enthusiastic about testing digital tools, something which enriched the discussions in the arena, as provocative questions had to be dealt with.

The work with specific cases allowed the architectural offices to test new ideas together with students and academic staff. In one of the cases, a real design proposal was built; in another case, new digital assessment tools were developed and implemented in the architectural firm's design process.

The common workshops and the push from the researchers to test innovative digital tools resulted in one office setting up a new R&D position at the office.

Outcomes: The project produced a large number of master's theses and some scientific publications, which are all summarized in a co-authored popular science book (Jensen, 2018). A final seminar book release attracted an audience of nearly 100 participants in Denmark, which also points to a broader interest and the potential applicability of the results.

SIRen – Sustainable Integrated Renovation

Aim and approach: SIRen is funded as a strong research environment connecting different disciplines (civil engineering, architecture, economy, sociology, heritage studies, etc.) from 10 universities and research institutes with over 30 building sector actors (property owners, consultants, contractors, etc.), governmental authorities, regional, and municipal agencies, and other non-governmental organizations. The aims are to develop and share knowledge and support innovation in sustainable renovation and to support innovation in renovation. The larger arena meets twice a year while small sub-groups have been formed to carry out both knowledge-first and more process-oriented projects, notably in connection to four real-world innovation laboratories (Mjörnell et al., 2015).

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Learnings and innovation: The strength of this large project is that it connects multiple disciplines and companies and can focus on a large variety of aspects of sustainable renovation. The challenge is to keep up the interest of all parties, including both academia and industry. Some participants have dropped off due to other priorities and because they perhaps did not manage to connect to some of the main activities in the arena. As in the other projects described, the replacement of employees from engaged organizations is also a challenge in this project.

The project is still ongoing, and the aim is to deliver a process model to support sustainable renovation. Parts of this model have already been tested in the real-world laboratories with good results (Femenías et al., 2017; Stenberg, 2015).

A recent survey among participants received more than 40 responses (Mjörnell, work in progress) that reveal the value of the arena for networking, collaboration, and knowledge exchange, as the following examples illustrate:

- *"Get in touch with people whom I otherwise would not have met in such favourable circumstances."*
- *"Plenty of time for discussion."*
- *"Get in touch with others with similar research opportunities that you can make joint applications with."*
- *"The network as a whole and the composition as 'all' parts of the construction process are included, from major contractors to individual consulting companies, from national authority to municipality."*

Outcome: The project has resulted in a large number of scientific and popular science publications co-authored with the academic, industry, and public authorities and agencies. For a list of publication visit: renoverings centrum.lth.se/siren/. The project has had a wide outreach and has been presented widely nationally but also internationally. The project is connected to two national knowledge centres: the National Center for Renovation and the National Center for Sustainable Building.

Discussion

The presented cases confirm many of the earlier reported experiences with transdisciplinary projects. The ReBo project follows the outline of transdisciplinary research as described by Lang and co-authors (2012), without knowledge of these definitions. All projects involve elements of knowledge-first and of process-orientation (Miller, 2013; Wittmayer & Schäpke, 2014), thus adding to the evidence that Mode 1 and Mode 2 research partly overlap (Bresnen & Burell, 2013; Ziman, 1996). All of the projects were academia-driven, but to varying degrees. The 3iii project was more of a knowledge-first project and was led by the academic institution, something which led to collaboration problems with the partners. As already stated by Gluch and colleagues (2013), there is a risk that a too scientific approach, a "science push", can lead to disinterest among participants.

ReBo and STED were more process-oriented. The ReBo project experienced a lack of legitimacy for the research approach and the project management among industry partners, which is a common challenge for this type of project (Wittmayer & Schäpke, 2014). STED was at times weighed down by long discussions. The non-hierarchical knowledge production upheld in theory (Balsiger, 2004) can be difficult to reproduce in reality as this can lead to unfocused and long discussions. Transdisciplinary projects can also lead to conflicts when existing institutions and hierarchies are devalued (Berker & Bharathis, 2012). The experiences from 3iii most likely illustrate a suspicion that academic knowledge is inadequate for use in practice, as upheld by Argument and co-authors (1998).

In the following subsections, we highlight two aspects that we found are of major importance for developing knowledge and innovation through transdisciplinary projects. First, it is important to "maintain the space", which means to keep up the interest and the participation in the arena, otherwise the project will only be a Mode 1 project. Second, transdisciplinary projects take time. This second aspect is something that has been brought up by earlier literature in the field (e.g., Argument et al., 1998; Deprés et al., 2004; Gluch et al., 2014). However, in contrast to earlier literature that has focused on experiences from single transdisciplinary projects, we bring forward the meta-learning and innovation process built up by consecutive projects over a longer period.

Maintaining the space

One of the main challenges with transdisciplinary projects is to establish and maintain the process arena. As stated by Lang and co-authors (2012), it is important to have the right level and scale of participation. The participation should be manageable and maintained throughout the project. Although it can be argued that

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the projects are not long enough for knowledge production and the development of common language and cultures, they still take several years. Industry often works with shorter timeframes, and the transdisciplinary project participation is often disrupted as employees tend to change position in the company or employer.

Thus, it is important to establish a common understanding of both the problem and aim of the project. Boundary objects are useful; they can be concepts or definitions that make the discussion tangible at the same time as they are open for further interpretations. Our results show that, to maintain the arena and reach the best collaborations and innovations, it can help to focus on concrete cases or tasks and in smaller constellations. This is usually done by making sub-groups within a larger arena project (ReBo and SIRen) when entering the knowledge creation phase, that is, in phase two according to Lang and co-authors (2012). The motivation for knowledge sharing is related to an active participation (Gluch et al., 2013). At the same time, making subgroups will challenge the validity and legitimacy in the larger arena, and consequently the broader up-take, of the innovation. If the project consists of a small number of academics and many other stakeholders, making smaller sub-groups focusing on topics that interest all participants might overload the academics with work.

Maintaining the process arena will also be a question of resources among the participating stakeholders. Large companies are typically better able to pay for their employees to actively participate than small companies. In order to engage smaller-scale technical consultants and architect offices, it helps if they can be paid through the research funding. However, even if the organization and company have the resources to pay, their employees still need to be able to set aside other tasks so they are free to engage in the project. It is therefore better for the company if their immediate tasks correlate with the those of the research projects.

It takes time

Time is a crucial factor in transdisciplinary projects. For example, companies seek short-term solutions and results (and also need these to motivate their active engagement in a transdisciplinary project), whereas academic knowledge production takes time (Argument et al., 1998). The development of common cultures and perspectives, which are necessary to establish collaboration in the arenas, is also something that takes time (Gluch et al., 2013) and requires frequent meetings (Deprés et al., 2004).

Wittmayer and Schäpke (2014) argue for an "institutional space" provided by the university to support researchers with the extra time needed for facilitating the arena and for scientific publication. Our experience is that, even if scientific publication can be produced with the results from transdisciplinary projects, time is taken from scientific publication in order to maintain the arena, and also to produce reports and guides for the participating stakeholders. A further challenge, as we have experienced in Sweden, is that project reports typically must be produced in the local language, whereas the scientific publications typically must be in English.

The empirical material in this study shows how several transdisciplinary projects connect together. This has provided a continuous learning process that might be an alternative to the "institutional space", which the university might have difficulties in financing. Through these consecutive projects, a network with common problems and perspectives has been generated. Results as well as working methods from one project have been taken into the next project (Figure 2). For example, preliminary results and theory on innovation processes developed in Demo04/06 were tested and further developed in 3iii, and were later on used in STED. Furthermore, the process matrix for integrated sustainable renovation developed in Rebo has been used in SIRen and in the STED project.

This continuity has helped the building up of sustainable networks. One of the architect firms participated in four of the presented projects but with different employees and varying competences (e.g., environmental specialist, designer, and social expert). Some of the other companies joined two of the presented projects. Most of the industry partners joined Rebo and later on SIRen which both focus on renovation (Figure 3). The established networks, in which common understanding of problems, have been an advantage when engaging the same organization in new projects.

Finally, as discussed by Lang and co-authors (2012), outcomes from transdisciplinary projects are not only tools, projects, or processes. Personal insights also result, as expressed by a participant in the ReBo project in the opening quotation for this article: *"We had the technical part ready but realized that this was the simple part of the challenge."* Our experience is that the personal insights from discussions in the process area is an important outcome and highly valuable for academics and other participants. However, as shown by 3iii

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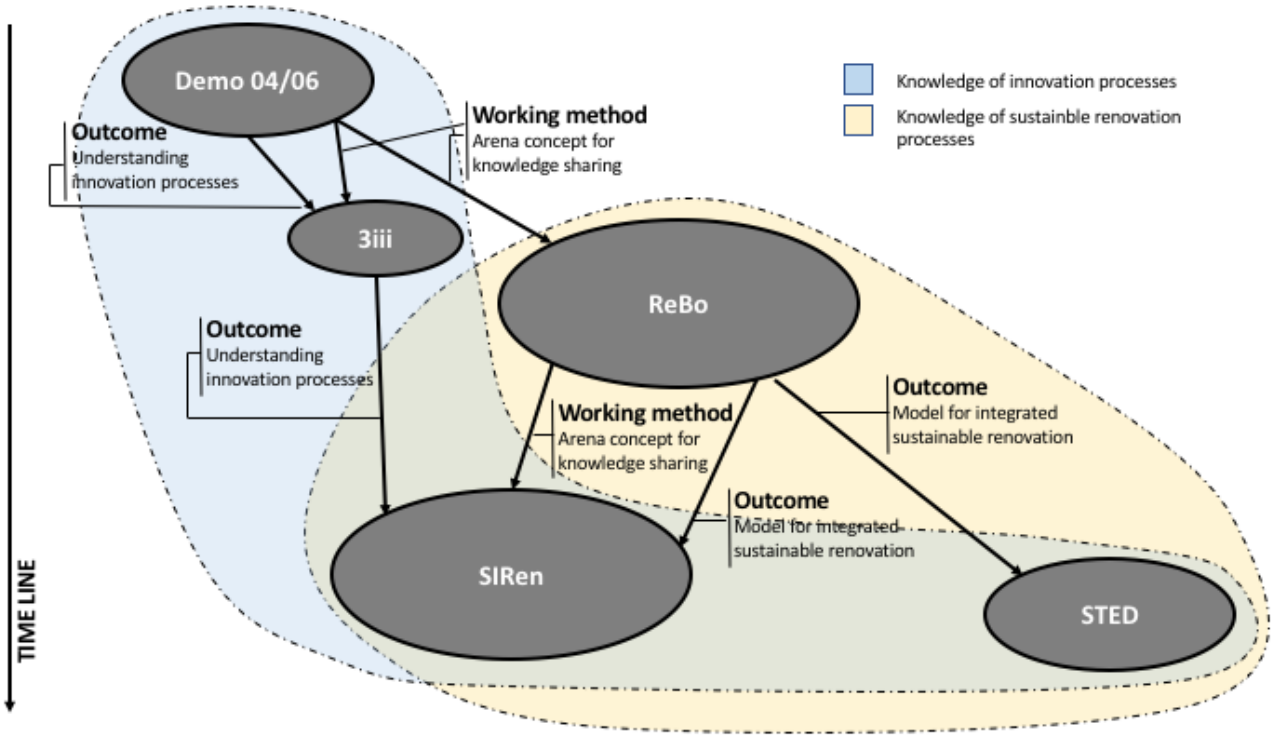

Figure 2. Relationship and knowledge flows between the five transdisciplinary projects

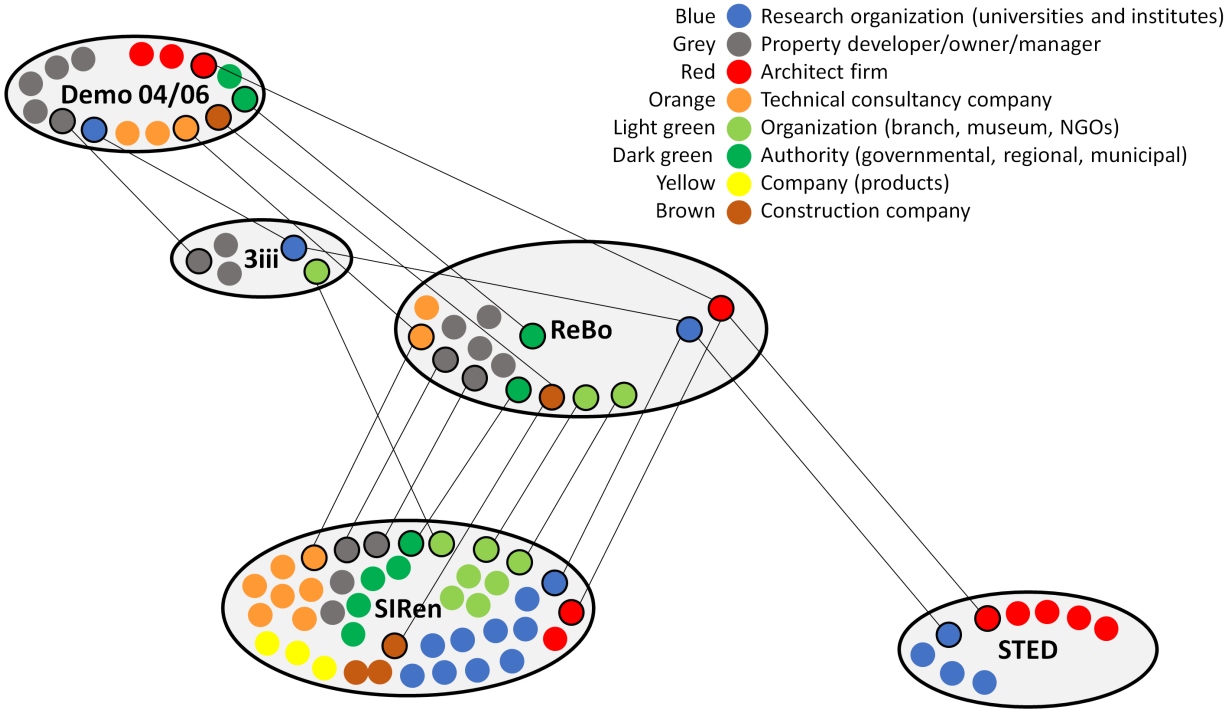

Figure 3. The actor network representing the participating organizations in the five transdisciplinary projects and highlighting organizations that have been involved in two or more projects. One dot represents one participating organization and the different colours represent different types of participating organizations.

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and ReBo, for example, these projects have also resulted in more direct support for innovations such as tools for sustainable renovation that have been put into practice.

Conclusions

Transdisciplinary research offers many opportunities, but it also involves many challenges. One of the most important experiences we wish to transmit is the importance of time. It takes time to build up networks, trust, and common perspectives. But, it also takes time to develop knowledge and innovation. Often, one project is too short, and we would advocate for planning for continuous projects to reach sustainable results.

Our practical suggestions for others wishing to engage in transdisciplinary research are:

- Read literature with theoretical definitions as well as practical experiences and guidelines for how to carry out a transdisciplinary project. Summarize important points in a project set-up document.
- Establish an arena with interested partners with competences that you think are useful, and keep the door open for the addition of more partners and competences to join.
- Plan for how to maintain the larger arena and the interest over time. Frequent meetings are needed, especially in the initial phases, in order to define common problem views and aims.
- Describe common aims, the approach and leadership of transdisciplinary research, rules of conduct, as well as expectations of each participant, which should be made available to all initial participants and newcomers during the whole project.
- If you establish a larger national arena, local sub-projects are needed for focused work in parallel with common activities in the larger group. Search for boundary objects (e.g., definitions, frameworks, models) that make the discussions tangible while still open for interpretations.
- In order to reach actionable and usable knowledge and innovation, it helps to focus work around real problems or cases, ideally in smaller groups.
- Search for opportunities to actively engage the participation of industry and public actors (in terms of time and financial resources), especially if they should be part of an innovation process.
- Share the workload: if possible, encourage non-academic partners to write case reports or popular trade articles, or to co-author articles.
- Make sure to establish a good network with possibilities for consecutive projects in order to further develop common understandings and innovation.

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About the Authors

Paula Femení as is an Associate Professor in the Department of Architecture and Civil Engineering at Chalmers University of Technology in Gothenburg, Sweden. Femenías works mainly in transdisciplinary and collaborative research projects with the aim of understanding and supporting innovation towards more sustainable building and transformation of the built environment. A special interest is the links between architectural design and long-term environmental, economic, cultural, and social sustainability. Femenías conducts research with others within SIRen (strong research environment for Sustainable Integrated Renovation), the Centre for Residential Architecture at Chalmers, and HSB Living Lab.

Liane Thuvander is an Associate Professor in the Department of Architecture and Civil Engineering at Chalmers University of Technology in Gothenburg, Sweden. Her research interests concern the field of sustainable building, especially with regards to the visualization of environmental and social aspects in existing buildings; sustainable integrated renovation; and implementation of sustainable building knowledge in practice. With others, she develops visualization strategies and methodologies for spatial value mapping involving participatory approaches in renovation and transformation of neighbourhoods. A major part of Thuvander's research is carried out in interdisciplinary or transdisciplinary environments with partners from academia, municipalities, NGOs, authorities, and a number of actors in the construction sector such as property managers, architects, and technical consultants.

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